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OPTIMIZING NAVY WHOLESALE INVENTORY POSITIONING

by

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OPTIMIZING NAVY WHOLESALE INVENTORY POSITIONING

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ABSTRACT

Naval Inventory Control Point (NAVICP) manages more than 186,000 Depot Level Repairable (DLR) line items in its wholesale inventory. It positions this materiel within a distribution network of 23 Defense Logistics Agency Depots and the privately owned Premium Transportation Facility (PTF). NAVICP plans to reduce materiel distribution time and optimize use of the distribution network to comply with mandated reductions in requisition response time. This thesis develops an Integer Linear Program (ILP) that positions one or more line items to achieve minimum distribution time subject to cost and other constraints. It derives a 57 line item test set composed of DLRs most likely to benefit from re-positioning: items with recent and projected demand and low weight. It also finds a simplified six-mode transportation scheme and an aggregated customer scheme that renders an ILP that is simple to use and captures the relationships that exist within the distribution network. Extensive analysis of the distribution network using the ILP indicates the Navy can cut response time and distribution cost by better strategic positioning of wholesale inventory within the existing network. These savings can be achieved by increasing use of PTF and considering use of storage depots not co-located with Navy activities.

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LIST OF ACRONYMS

AFB	Air Force Base
ALC	Air Logistics Center
AMC	Air Mobility Command
APHT	Aerial Port Holding Times
APOD	Aerial Port of Debarkation
APOE	Aerial Port of Entry
ASO	Aviation Supply Office
CRR	Carcass Return Rate
DAAS	Defense Automatic Addressing System
DD	Defense Depot
DDC	Defense Distribution Center
DDS	Defense Distribution System
DLA	Defense Logistics Agency
DLR	Depot Level Repairable
DMRD	Defense Management Review Decision
DOD	Department of Defense
DODAAC	Department of Defense Activity Address Code
DODMDS	Department of Defense Materiel Distribution System
DOP	Designated Overhaul Point
DPT	Depot Processing Time
DTS	Defense Transportation System
FISC	Fleet Industrial Supply Center
FSC	Federal Supply Class
FSG	Federal Supply Group
GSA	General Services Agency
ICP	Inventory Control Point
ICPT	Inventory Control Point Processing Time
ILP	Integer Linear Program
IM	Item Manager
LI	Line Item
LRT	Logistics Response Time
MOE	Measures of Effectiveness
NADEP	Naval Aviation (Repair) Depot
NAS	Naval Air Station
NIIN	National Item Identification Number
NIS	Navy Inventory System
NSN	National Stock Number
PDS	Primary Distribution Site
POD	Port of Debarkation
POE	Point of Entry
POET	Point of Entry Time
MRO	Materiel Release Order
PTF	Premium Transportation Facility
RDD	Required Delivery Date
RP	Requisition Priority
RSR	Repair Survival Rate

RST	Requisition Submission Time
RTT	Requisition Take Up Time
SAILS	Strategic Analysis of Integrated Logistics Systems
SPCC	Ship's Parts Control Center
TP	Transportation Priority
TT	Transportation Time
UIC	Unit Identification Code
UICP	Uniform Inventory Control Processing System
UMMIPS	Uniform Materiel Movement and Issue Priority System
UPS	United Parcel Service
VC	Variable Cost
WWX	World Wide Express

EXECUTIVE SUMMARY

The Navy plans to reduce materiel distribution time and optimize the use of the distribution network to comply with mandated reductions in requisition response time. This thesis shows how the Navy can cut response time and distribution cost by better strategic positioning of wholesale inventory within its available distribution network. These savings can be achieved by increasing use of the Federal Express owned and operated Premium Transportation Facility (PTF) and considering use of storage depots not co-located with Navy activities. These conclusions follow extensive analysis of the distribution network using an Integer Linear Program (ILP) that positions one or more line items to achieve minimum distribution time subject to distribution cost and other constraints. This study derives a 57 line item test set composed of Depot Level Repairables (DLR) most likely to benefit from re-positioning: items with recent historical demand (last two fiscal years), high projected demand (four or more per year) and low weight (less than 150 lbs). It also derives a simplified six-mode transportation scheme and an aggregated customer scheme (40 demand regions) that renders an ILP that is simple to use and captures the relative relationships that exist within the distribution network.

Naval Inventory Control Point (NAVICP) maintains worldwide control and visibility over more than 371,000 line items of Navy wholesale materiel, including more than 186,000 DLR line items. NAVICP efforts encompass all aspects of product management including buying, repairing, distributing, issuing and disposing of materiel. Although NAVICP directs distribution and issuance of Navy wholesale materiel, it does not manage any of the distribution activities. NAVICP positions these items within a distribution network composed of Defense Logistics Agency (DLA) Defense Depots (DD) and the PTF.

DLA currently operates 23 DDs worldwide. These facilities receive, store and issue DLA and service managed materiel. DLA, however, does not decide where Navy materiel is positioned within its network. NAVICP Item Managers (IM) determine where to position materiel within the network by considering factors including location of historical demand, proximity to overhaul depots, special requirements and their own discretion. These IMs currently position wholesale materiel primarily at eight DDs co-located with Navy activities.

Federal Express manages and operates the PTF in Memphis Tennessee under a DLA contract. This contract is available for use by all services. The PTF guarantees 24 hour delivery inside the continental United States and 48 hour delivery outside the continental United States. The overseas deliveries are to the nearest port of debarkation, and the associated guarantee does not include the time delay associated with customs clearance. The PTF is a sole source facility and unlike DDs, ships all items via air, without regard to requisition priority. The Navy currently has designated about 800 line items for positioning at the PTF.

This thesis analyzes positioning of single DLR line items within seven network permutations and considers implications of aggregated results on positioning strategies. The size of the distribution system precludes evaluating all possible item, supplier, depot and customer combinations. This study uses actual supplier and depot locations as the basis for cost and time calculations but uses 40 demand clusters derived through a geographic aggregation scheme as the basis for demand location. This demand data is based on October 1996 to September 1998 Requisition History provided by NAVICP.

Testing reveals important insights about product characteristics affecting positioning. Low weight items tend to achieve minimum distribution cost solutions at DLA Depots because they incur lower depot processing costs relative to the PTF and because overseas freight rates offered by Air Mobility Command are lower than those offered by Federal Express through the

World Wide Express Contract. Higher weight items tend to prefer the PTF when demand is significantly dispersed, especially to overseas locations, because World Wide Express freight rates tend to be lower than AMC rates (at higher weights). Even when we test positioning within networks consisting solely of Navy co-located Depots and the PTF, about one third of these items find lowest distribution cost and logistics response time (LRT) solutions at the PTF. Low weight items with relatively high overseas demand tend to prefer depots (not necessarily Navy co-located depots) closest to AMC Aerial Ports of Embarkation to minimize transportation cost.
Comparison of networks composed of Navy co-located Depots to networks composed only of non-Navy co-located Depots (plus the PTF) show that average distribution costs increase slightly while average LRT drops about 25 percent; deleting Navy co-located DDs from the network has little impact on distribution cost for these items and actually decreases LRT, due in large part to the impact of the PTF.

I. INTRODUCTION

Naval Inventory Control Point (NAVICP) currently manages more than 186,000 Depot Level Repairable (DLR) line items worth $28 billion (Evans 1999) (Ackert 1999). It positions these items within a distribution network of 23 Defense Logistics Agency (DLA) Defense Depots (DD) and the privately owned and operated Premium Transportation Facility (PTF). NAVICP, however, primarily uses eight of these 23 DDs: six co-located with Fleet Industrial Supply Centers (FISC), one co-located with the Aviation Repair Depot at Marine Corps Air Station Cherry Point North Carolina and one located near Naval Station Ingleside Texas. NAVICP plans to reduce materiel distribution time by optimizing use of the distribution network. This thesis analyzes NAVICP's distribution network using an integer linear program that positions one or more individual items within the network to provide the minimum distribution time subject to cost and other constraints.

A. THESIS OUTLINE

The rest of this chapter presents an overview of Navy Inventory Management. Chapter II discusses Distribution System Studies and related literature on data aggregation. Chapter III provides the model and details data characteristics and assumptions. Chapter IV discusses computational experience. Chapter V presents conclusions and recommendations.

B. OVERVIEW OF NAVY INVENTORY MANAGEMENT

This section provides some basic tenants of Navy Inventory Management, including Navy materiel and the associated classification/identification system, wholesale inventory management (NAVICP), DLR sourcing, physical distribution and logistics response time (LRT).

1. Navy Inventory System (NIS)

NIS provides end users with "secondary items of supply for weapons, weapons support systems and equipment with aviation or marine applications (Naval Supply Systems Command (NAVSUP) 1996)." In this context, NIS manages items at the wholesale level and not items managed by other non-Navy entities such as the General Services Agency (GSA) or other service ICPs. NIS items divide into two categories: consumables and DLRs. This thesis only considers DLRs.

DLRs fall into three categories: component parts, End Items and Modification kits. DLRs are items that are economical to repair but have a complexity requiring repair at a depot. Although DLRs make up about half of the total line items in the NIS, they are inherently more costly, complex and harder to manage than consumables because as long as they are demanded, they continue to be repaired, restocked and reused until destroyed, lost or beyond economic repair. Component parts are used in combination with other items to make up a system or End item. End items, which are intended for use on a stand-alone basis, are a combination of components, including DLRs (e.g., ships, trucks). Modification kits, like end items, are a combination of components but "… are assembled by the systems command [e.g., Naval Air Systems Command] and managed by the ICP to be issued as one stock number to customers for use in altering the capability, function or performance of an end item or a component of an end item (NAVSUP 1992)."

Every item managed within the Navy Supply system (and in the Federal Supply System) has a National Stock Number (NSN), a 13 digit code that uniquely identifies the item. Requisitioners use NSNs for ordering items stocked by the Supply System. NSN contains both a four digit Federal Supply Class (FSC) and nine digit National Item Identification Number (NIIN). The FSC identifies the federal materiel category while the NIIN uniquely identifies the part. FSC breaks down into a two-digit Federal Supply Group (FSG) and two-digit Product class. FSG identifies the major materiel category while product class more narrowly defines the kind of

materiel included within the FSG. Each NSN can also be categorized by an associated two character alphanumeric materiel cognizance symbol (cog) which identifies the ICP or other federal office or agency responsible for its management. Cogs "7E", "7G","7H", "7R", "7Z" refer to DLRs managed by NAVICP. This thesis classifies "7E", "7G", "7H" and "7Z" as "Non-Aviation" cogs and "7R" as "Aviation" cog. Figure 1.1 provides a specific example of categorizations for a particular NSN.

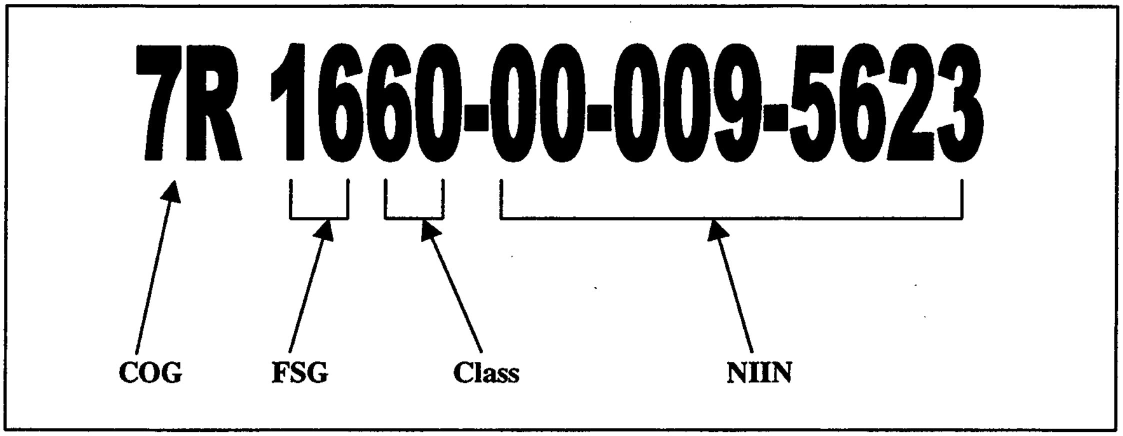

Figure 1.1: Cog and NSN Example

Figure 1.1 shows the cog and NSN for an item named "Air Pressure Regulator". "7" indicates the item is a DLR managed by NAVICP. "R" means the part is an aviation item. "16" identifies the item as belonging to FSG "Aircraft Components and Accessories". "60" indicates the item belongs to "Air Conditioning, Heating and Pressuring Equipment" Class. The NIIN uniquely identifies the item.

The NIS operates in two echelons: retail consumer level and wholesale level. Retail consumer level activities consume or use retail stocks (consumables and DLRs) to support their own operations. Activities falling into this category include ships, submarines and shore bases. Wholesale activities carry items to support worldwide demand, including replenishment of the retail level and all levels of maintenance. This thesis only considers wholesale DLR positioning; retail level DLRs by their nature are co-located with the customer location.

2. NAVICP

NAVICP, the only Navy ICP, maintains worldwide control and visibility over Navy wholesale stocks. Its present organization is the result of the October 1995 consolidation of the Navy Ships Parts Control Center (SPCC) with the Naval Aviation Supply Office (ASO). These entities retain their previous geographic sites but are now referred to as NAVICP Mechanicsburg (NAVICP-M) and NAVICP Philadelphia (NAVICP-P). NAVICP-M manages roughly 260,000 line items worth $8.0 billion (including 117,300 DLR line items worth $7.1 billion) in support of the surface and subsurface Navy (Evans 1999). NAVICP-P manages about 111,000 line items worth $21.5 billion (including 68,800 DLR line items worth $21.0 billion) in support of Naval and Marine Corps Aviation. (Ackert 1999)

NAVICP efforts encompass all aspects of product management including buying, repairing, distributing, issuing and disposing of materiel. Although NAVICP directs distribution and issuance of Navy wholesale materiel, it does not manage any of the distribution activities. Defense Management Review Decision (DMRD) 902 shifts responsibility for physical distribution from the services to DLA (Holmes 1994).

NAVICP determines Navy wholesale inventory levels using an adaptation of "lot size reorder point" models described in chapter 4 of *Analysis of Inventory Systems* (Hadley and Whitin 1963). These models reside within the Uniform Inventory Control Program (UICP) and determine optimal inventory level requirements by "minimizing an average annual variable cost equation composed of order costs plus holding costs plus shortage costs (NAVSUP 1992)." "UICP is a highly automated, integrated system that, except for provisioning, provides automated applications software support for nearly the full range of NAVICP functions, including procurement and financial control (NAVSUP 1996)."

Item Managers (IM) at NAVICP "have the primary responsibility for ensuring secondary item parts are available where and when needed to support operations of the fleets, naval shore activities and other customers (NAVSUP 1992)." At the end of Fiscal Year 1997, NAVICP-M

had 108 IMs and NAVICP-P had 257 IMs (NAVICP 1997). Individual IMs manage hundreds or thousands of line items of materiel. These efforts include materiel procurement, repair coordination, inventory positioning, excess materiel disposal, budgeting and supply performance analysis. IMs rely on UICP reports to effectively manage their line items. They consider UICP recommendations, especially in determining where to position new procurements or returns from repair. UICP recommends wholesale inventory positioning based on the historical percentage of worldwide demand (i.e., if 25% of worldwide demand is in Norfolk, then 25% of the worldwide inventory should be positioned there). However, IMs may choose to ignore the positioning recommendation if there are overriding factors such as:

- lack of proper storage capacity or handling capability;
- proximity of repair activities to storage depots;
- minimizing transportation costs (send all to one location instead of multiple locations); and
- minimizing multiple locations based upon small size of requirement.

UICP positioning recommendations and other NAVICP positioning policies do not necessarily minimize LRT or distribution cost since:

- UICP does not consider different depot to depot inventory transaction costs such as receipt and issue costs;
- UICP does not consider inbound and outbound transportation costs;
- UICP does not consider the privately run PTF as a possible distribution point;
- DLA Distribution Facilities not co-located with Navy FISCs are not normally considered as distribution points (except for DDs Cherry Point NC and Ingleside TX that are co-located with a Repair Depot and Navy Base/FISC San Diego Detachment, respectively);
- Current NAVICP policy generally requires that Ready-for-Issue DLRs returned from repair depots be positioned at the closest DD to minimize transportation cost - without regard to projected demand location (MacMillian 1998);
- The UICP redistribution function (recommends inventory movements between depots to balance projected regional demands) has been turned off to save transportation costs (Engelman 1998): this may increase LRT; and
- UICP does not explicitly consider LRT from distribution depot to customer.

A deficient positioning methodology can contribute to higher inventory management costs and LRT. This thesis considers both cost and LRT in deriving an optimal positioning strategy.

3. DLR Sourcing

DLRs currently in stock in the NIS result from either new procurement or repair of existing items. These items originate from one of three sources: manufacturers, government operated repair depots, or commercially operated repair depots. NAVICP IMs control the procurement of DLRs. With the assistance of UICP demand forecasts and DLR survival rates (surviving use and return into the supply system and surviving the repair process), IMs determine how much wholesale inventory comes back into the NIS from repairs and how much new inventory must be procured.

Designated Overhaul Points (DOPs) perform DLR repair. DOPs change over time reflecting the capability and capacity of government sites as well as competitive commercial overhaul contracts. The MRIL (Master Repairables Item List), a database within UICP, identifies the DOP(s) associated with a particular DLR. Table 1.1 presents a summary of the

	Navy DOPs	Commercial DOPs	Other Service DOPs	Totals
Aviation DLRs	4	254	11	269
Non-Aviation DLRs	29	765	10	804
Totals	33	1,019	21	1,073

Table 1.1: Active DOPs

This table presents the number and types of DOPs that performed repairs on aviation and non-aviation DLRs during fiscal year 1998 (MacMillan 1999).

DOPs. Many of the commercial repair activities also manufacture the item. Government repair activities include Naval Aviation Depots (NADEPs), Naval Weapons Stations, Naval Shipyards, and repair activities of other services such as the Air Force Air Logistics Centers (ALCs). Current NAVICP policy is to stock repaired materiel at one of the four CONUS FISCs:

"typically, the stock point designated will be the one closest to the [repair] depot (MacMillan 1998)." NAVICP policy previously specified assigning multiple stock points for items coming out of repair but that practice was changed to save money on shipping costs (MacMillan 1998). NAVICP currently does not stock organically repaired materiel at the PTF because it is subject to double receipt and issue charges (once from DLA and once from the PTF) (Porter and Emerick 1998). Navy repair depots are located near DDs but these repair depots have no capability for shipping materiel and such items must be sent to the DD for packaging and shipping. If the items are then sent to the PTF, they would again incur receipt and issue charges. We disagree with this stance since commercial DOPs also incur issue and receipt costs when processing items for repair and such costs are likely charged to the government, albeit as an element of the contract price.

Acquisition sources for DLRs are identified by "CAGE" codes, five digit codes that are associated with all stock numbers (NSNs). These codes also change over time as new sources are acquired. As of 1999, there are more than 1,000 procurement sources for DLRs (Engelman 1999).

4. DLA

NAVICP controls its wholesale inventory positioning within DLA's distribution network. DLA's Defense Distribution Center (DDC) in New Cumberland, PA, manages the physical distribution of Navy wholesale inventory with the exception of materiel positioned at the PTF. DDC, however, does not determine where to store Navy managed materiel within its network. DDC operates 23 DDs with an aggregate storage capacity of 457 million cubic feet (DLA 1999a). These facilities receive, store, and issue DLA and Service managed materiel. In 1998, DDC Depots processed 19.5 million transactions (receipts and issues) and managed 4.9 million line items of materiel with a value of $95.8 billion (DLA 1998a). A map of DLA's current distribution network is provided in Figure 1.2. With the exception of Columbus, Richmond, Susquehanna, and San Joaquin, these sites are co-located with a military activity. DDs co-located with Navy stock points (FISCs) include those in San Diego, Puget Sound, Jacksonville,

Norfolk, Pearl Harbor and Yokosuka. DDs located near other Navy activities include Corpus Christi (FISC Detachment San Diego and Naval Station, Ingleside TX) and Cherry Point (Marine Corps Air Station (and Repair Depot) Cherry Point NC).

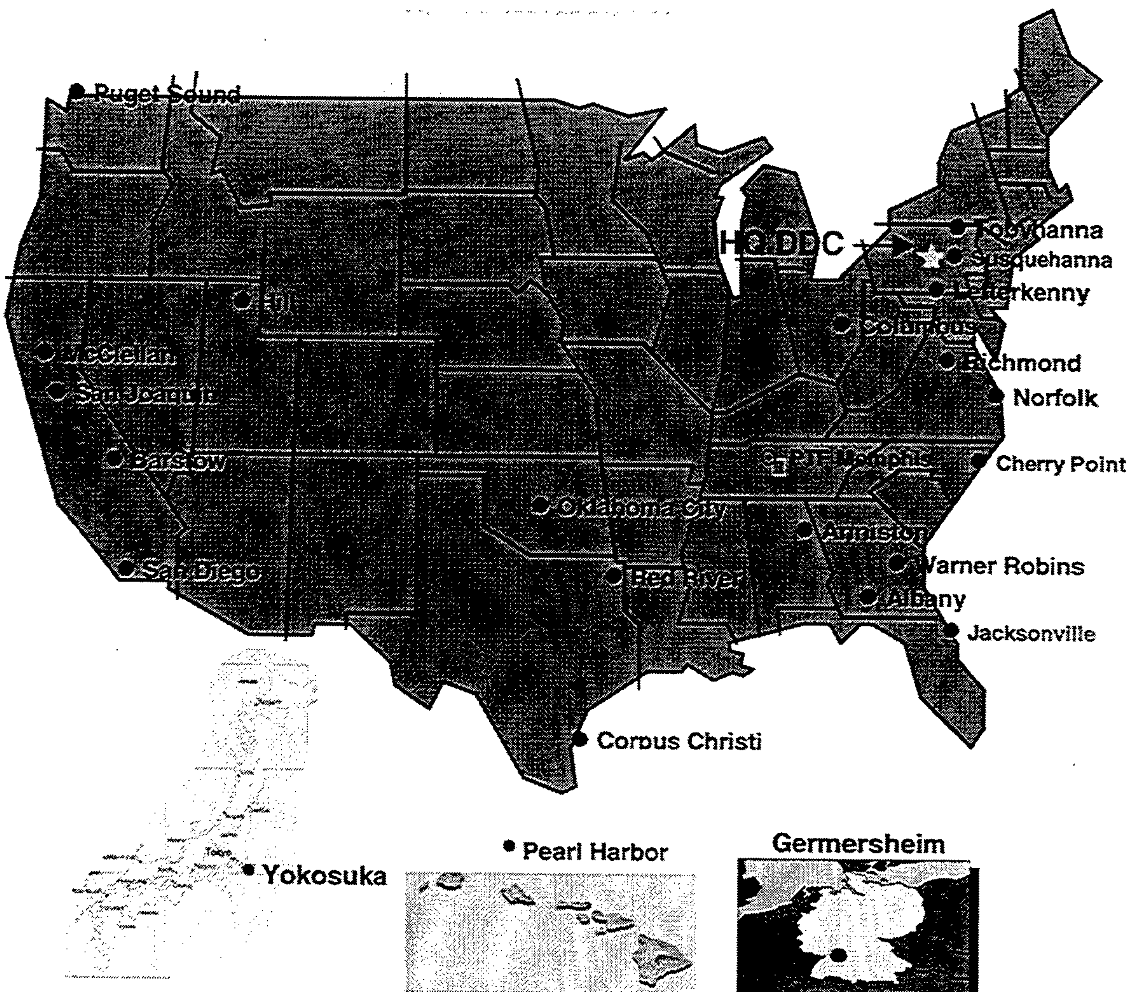

Figure 1.2: Map Of DLA's Distribution Network

Modified from "DDC_Locations" dated 01 February 1999, a slide provided by DDC. This figure presents DLA's distribution network, which includes 23 DDs and the PTF: three of the DDs are located OCONUS. DLA's Primary Distribution Sites (PDS) are located at Susquehanna PA and San Joaquin CA. These sites are modern, high volume facilities and considered DLA's most efficient cost effective DDs.

DLA has a contract with Federal Express Inc. (FedEx) to manage and operate the PTF in Memphis, Tennessee, also the site of FedEx's main hub (Gotwalt 1998). Under this "expedited shipment" contract, FedEx guarantees 24 hour delivery inside the continental United States (CONUS) and 48 hour delivery outside the continental United States (OCONUS); OCONUS deliveries are to the nearest port of debarkation and the associated guarantee does not include the time delay associated with customs clearance. The PTF, unlike DDs, ships all items via air, without regard to requisition priority. All military services may use the "Premium Service" contract.

Premium Service shipments currently constitute about 1.4 percent of the total PTF throughput (including commercial customers) of 1,000,000 parcels per day (Sample 1999). Unlike DDs, PTF capacity is essentially unlimited as FedEx can expand warehousing (lease additional space) as necessary to meet customer's needs.

NAVICP-M has moved 33 line items of materiel to the PTF since July 1996 as part of a prototype program (Porter and Emerick 1998) and will move 457 more items there in 1999 (Emerick 1999a). NAVICP-P currently has 320 line items at the PTF (Porter and Emerick 1998).

DLA provides broad guidance to services on selecting inventory candidates for the PTF: "the Premium Service option is targeted to satisfy those customers who wish to limit investment in high dollar value items, purchase commercial off the shelf stock, speed-up repair and return of critical parts, hold new procurement until reorder levels are established or those who wish to reduce the expense and hassle of storing certain sensitive and controlled items (DLA 1999b)." PTF Inventory selection criteria are in a state of flux. A joint DLA/ICP Stock Positioning Integrated Product Team (IPT) is currently considering formal PTF stock positioning criteria (DLA 1999b). NAVICP initially selected candidates for the PTF in 1996 based on [then existing] DLA recommended (Navy interpreted) criteria: high volume (12 or more demands annually), high dollar value (greater than $5,000 unit cost), low weight (less than 150 pounds per unit), and a history of high priority demands (typically TP 1 demands) (Robillard 1997). For items moving

in 1999, NAVICP's selection criteria includes only: weight less than 20 pounds, annual demand of four or more for DLRs and annual demand of 20 or greater for consumables (Emerick 1999b).

5. LRT

Supply response time, also known as LRT, represents the time from submission of a materiel requisition by a customer until the time the customer electronically acknowledges receipt to the Defense Automatic Addressing System (DAAS). LRT has the following segments (in chronological order): Requisition Submission Time (RST), Point of Entry Time (POET), Inventory Control Point Processing Time (ICPT), Depot Processing Time (DPT), Transportation Time (TT), the "ABYSS" and Requisition Take Up Time (RTT). RST is the time between requisition Julian date and receipt at the DAAS which automatically directs the requisition to the specified Point of Entry (POE) (generally a FISC). POET is the time from POE receipt to ICP referral. ICPT is the time between referral from the POE to the ICP and the time the ICP issues the Materiel Release Order (MRO) (authorization by NAVICP to release wholesale stock) to the depot. ICPT includes backorder time for not carried or not in stock items. DPT is the time between depot receipt of the MRO and materiel shipment. TT is the time from depot shipment to delivery at the local retail site. The "ABYSS" represents the time from delivery at the local retail site to physical receipt by the customer. RTT is the time from physical receipt by a given customer to the time DAAS receives the receipt acknowledgement.

Vice President Gore's National Procurement Review requires the Navy to reduce LRT by 50 percent no later than fiscal year 2000 (NAVSUP 1998). The Navy's goal is, by September 2000, to reduce LRT from a 1998 baseline of 46 days to 23 days (Engelman 1999). In late 1998, NAVICP and the Naval Supply Systems Command (NAVSUP) jointly formed Process Improvement Teams to analyze the existing processes in each LRT segment and to propose changes to achieve further reductions. This thesis addresses only the DPT and TT segments of LRT.

A requisition's priority (RP) and required delivery date (RDD) influence both the depot to customer time (DPT and TT) for stocked materiel and the mode of shipment(s) selected by the shipping activity (e.g., DLA Depot). All requisitions fall into one of three Transportation Priorities (TPs) based upon their RP and RDD, as shown in Table 1.2. The Uniform Materiel Movement and Issue Priority System (UMMIPS) sets time standards for all segments of LRT. These standards do not apply to requisitions for materiel unavailable in the distribution network. Table 1.3 presents a summary of UMMIPS standards for the DPT and TT segments. Shippers use these standards in conjunction with the requisition TP to determine the most economical transportation mode to meet the RDD or, in its absence, the maximum UMMIPS time in a TP.

TP	RP	RDD
1	01 to 03	999, RDD under TP1 UMMIPS standard
2	04 to 15	N__*, E__*, 444*, 555*, 777*, RDD less than 8 days from requisition date.
3	04 to 15	Blank RDD, RDD greater than eight days from requisition date.

Table 1.2: TP Breakdown

Summarized from DOD Materiel Management Regulation 4140.1-R, Appendix 8. This table provides the RP and RDD for determining requisition TP. Shippers use TPs to determine applicable time standards and the shipment mode(s) required to meet these standards. Asterisks signify expedited handling codes.

The Defense Transportation System (DTS) moves Navy DLRs using the modes identified in Table 1.4. Although this table does not account for multiple mode shipments, it indicates that more than 98 percent of shipments moved in just ten of the 29 available modes. More importantly, the table shows more than 60 percent of these shipments moved in an expedited manner by surface and air small package carriers. Naval Transportation Support Center (NAVTRANS) personnel agree with these findings and furthermore indicate that almost all overseas DLR shipments move by air (mostly through Air Mobility Command (AMC)) and

almost none by ocean surface methods (Boylan 1999). This study uses these findings to develop a simplified transportation mode scheme for use with model testing (described in Chapter III).

	AREA				
TP / LRT SEGMENT	**CONUS**	**A**	**B**	**C**	**D**
TP 1 Time Standards:					
Depot Processing Time	1.0	1.0	1.0	1.0	1.0
Transportation Time	1.0	4.5	4.5	4.5	6.5
Total DPT and TT Time for TP1	2.0	5.5	5.5	5.5	7.5
TP 2 Time Standards:					
Depot Processing Time	1.0	1.0	1.0	1.0	1.0
Transportation Time	4.0	6.5	6.5	6.5	6.5
Total DPT and TT Time for TP2	5.0	7.5	7.5	7.5	7.5
TP 3 Time Standards:					
Depot Processing Time	3.0	3.0	3.0	3.0	3.0
Transportation Time	9.0	19.0	19.0	19.0	24.0
Total DPT and TT Time for TP3	12.0	22.0	22.0	22.0	27.0

Table 1.3: UMMIPS Time Standards for DPT and TT

Summarized from DOD Materiel Management Regulation 4140.1-R. This table provides time standards by TP by area of destination for the DPT and TT segments of LRT. DPT is formally known as "Storage Site Processing, Packaging and Transportation Hold Time." TT may be composed of several legs but for purposes of this thesis it represents the time between shipment from depot and either arrival at the customer site within CONUS or arrival at the Point of Debarkation (POD) OCONUS. OCONUS areas are:
Area A: Alaska, Hawaii, Guam, Caribbean, Central America
Area B: United Kingdom, Northern Europe
Area C: Japan, Korea, Okinawa, Western Mediterranean
Area D: Hard Lift Areas, destinations not included in A thru C above as determined by USTRANSCOM (i.e. S. America, Eastern Mediterranean, N. Atlantic, Africa, Diego Garcia etc)

This chapter merely scratches the surface of the many factors and inter-relationships within the Navy's DLR distribution network. Clearly, however, the foregoing suggests that distribution costs and LRT may be reduced by considering alternative distribution policies and network permutations available, but not fully utilized, within the existing DLA network.

Description	Mode	Frequency	% of Total
Small Package Carrier	J	74,706	0.3818
Local Delivery	9	43,492	0.2223
United Parcel Service	5	19,925	0.1018
Air Freight / Express	Q	14,021	0.0717
Air, parcel post	H	12,044	0.0615
Military Airlift Command	F	8,819	0.0451
Motor, less truckload	B	6,830	0.0349
Bearer Walk thru	X	5,627	0.0288
Air Freight Forwarder	T	4,101	0.0210
Surface, Parcel Post	G	2,745	0.0140
Motor, Truckload	A	1,273	0.0065
Scheduled Truck	S	899	0.0046
Express Mail	7	583	0.0030
Rail, less carload	L	156	0.0008
QUICKTRANS	U	140	0.0007
Bill of Lading	P	88	0.0004
SEAVAN	V	39	0.0002
Water, river, lake	W	38	0.0002
Rail, carload	K	34	0.0002
Military Sealift Command	Z	29	0.0001
Government Truck	I	27	0.0001
Driveaway	D	24	0.0001
Intra-theater air lift	Y	18	0.0001
Armed Forces Courier	4	8	0.0000
Pipeline	8	4	0.0000
LOGAIR	N	4	0.0000
Organic Military Air	O	4	0.0000
Military Ordinary Mail	6	3	0.0000
Erroneous	0	2	0.0000

Table 1.4: Modes of Shipment of Navy DLRs

This table provides DLR shipment modes for the period August 1997 (database start date) to September 1998 and is derived from LRT files provided to NAVICP by DAAS. DAAS maintains requisition history information and the shipment mode shown is the last one on record (there may be more than one mode associated with a particular requisition). The LRT files used contain 271,800 requisitions, 76,000 of which have blank mode of shipment fields. NAVICP personnel indicate that requisitions with blank mode of shipment fields result from such data not being submitted to DAAS by the shipping activity (Diehl 1999). The derived percentages are based on 195,800 requisitions with shipping modes in the LRT files.

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II. RELATED STUDIES

This chapter discusses fundamentals of logistics planning and distribution network design and reviews studies of distribution networks to provide a basis for understanding the current effort.

A. LOGISTICS PLANNING AND DISTRIBUTION NETWORK DESIGN

The term "logistics" refers to "the art of managing the flow of materials and products from source to user (Magee, Copacino and Rosenfield 1985)." In this sense, logistics impacts most functional areas of large organizations and therefore, successful planning and execution of logistics-related functions becomes crucial to organizational success. Ballou [1992] defines logistics planning efforts as strategic, tactical or operational. Strategic planning is long term and considers time horizons greater than one year. Tactical planning covers an intermediate time horizon generally less than one year. Operational planning is short term and concerned with more immediate results. The amount of data available to support these three planning levels generally varies inversely with time. Therefore, strategic planning by nature is supported by data that is often vague and incomplete while the shorter term planning horizons have commensurately more and more accurate data. With this basis, we now consider distribution network design.

Distribution network design is a long-term effort and necessarily occurs at the strategic planning level. "Logistics strategy decisions involve the number, size and location of distribution centers, the choice of channels, the selection of transportation modes [and] the deployment of inventories (Magee, Copacino and Rosenfield 1985)." This thesis examines characteristics of the Navy's DLR distribution network, a subset of the NIS that essentially operates as an entity within DLA's distribution network. Navy IMs determine how to satisfy customer demand, in part, by deciding where to position wholesale DLRs. In deriving the appropriate configuration of such a distribution network, we need to consider the measures of effectiveness (MOE) used to determine network performance. Navy MOEs include LRT and distribution cost. The commercial sector shares these MOEs:

> The standard problem we address is to find a minimal annual cost configuration of a company's production and distribution network that satisfies product demands at specified service levels [LRT] (Geoffrion and Powers 1995).

In the Navy's case, the "production" dilemma involves the source (i.e., buying new DLRs from the manufacturer or obtaining repaired items from DOPs), timing and quantity of items to procure. This thesis does not address the IM (or UICP's) role in determining either stocking levels or replenishment rates. Rather, this study analyzes strategic positioning of wholesale DLR inventories to meet projected customer demand given product sourcing from new procurement and repair. This study considers only those strategic logistical issues that are pertinent to optimizing DLR positioning of single or multiple line items within permutations of the existing network and does not address adding new depots or closing existing ones.

B. PREVIOUS STUDIES OF DISTRIBUTION NETWORKS

This section reviews two previous studies of DLA distribution, "Department of Defense Materiel Distribution System (DODMDS) Study" and "A Multi-Commodity Network Design for the Defense Logistics Agency (Holmes Study)." It also considers studies of civilian distribution networks. These studies are useful for comprehending DOD modeling issues and data aggregation.

1. Previous Studies of the DLA Distribution Network

The DODMDS Study analyzes the CONUS distribution systems of DLA and the four Services (collectively called DODMDS) and proposes an optimal distribution network to make them more efficient and responsive to individual Service needs. The study's recommendations have not been implemented. Its summary conclusions state, "... major savings [$100 million a year] might be possible through [nine depot] closures and by positioning certain categories of materiel closer to customers (DODMDS 1978)." Two models support these conclusions: a mixed integer linear programming model to minimize depot costs and transportation costs and a dynamic simulation model to evaluate system and depot capacity and responsiveness. The study derives data for these models through examination of system variables, including "commodities,

distribution facility locations and associated costs, sources of materiel, customers and transportation links (DODMDS 1978)," and develops aggregation techniques to facilitate model construction. Aggregated data consists of 15 grouped depot locations, 142 procurement source zones, 205 customer nodes and 27 product bundles. Data supporting this effort includes one year of demand (three quarters of 1975 and one quarter of 1976) history, capacities, costs and locations of 34 storage depots, 3.5 million line items of stocked materiel, 19,000 procurement sources and 50,000 CONUS customer locations (DODMDS 1978). This study includes all materiel managed by the Services except for: ammunition, bulk fuel, perishable subsistence, chemical, biological and radiological items, industrial plant equipment and major end items (e.g., aircraft, ships and strategic missiles) (DODMDS 1978).

The Holmes Study analyzes the DLA distribution network and proposes depot closure candidates to support planned 1995 budget reductions. At that time, DLA supported 45 thousand customers from 28 depots using more than ten thousand suppliers and over three million stocked line items (Holmes 1994). The study suggests that more than $300 million in annual savings can be achieved through reorganization and depot closures (Holmes 1994). It derives a model data set consisting of a single "Supersource", 28 depots, 29 products and 113 demand regions and finds closure candidates utilizing the Strategic Analysis of Integrated Logistics Systems (SAILS) model, "a mixed integer linear programming model used widely by a number of civilian organizations to make facility location decisions (Holmes 1994)." The Holmes Study exploits many of the techniques of the DODMDS study to derive product, customer, supplier and transportation mode aggregation schemes.

Demand stability and aggregation are two significant data issues for the DODMDS and Holmes Studies that are relevant to the current effort.

The DODMDS Study claims that using one year of actual demand in their models is valid since customer demand patterns within DOD vary relatively little due to an unchanging customer base (DODMDS 1978). Holmes observes that Hobbs and Lanagan [1992]

had refuted that assumption finding that annual DLA demand patterns fluctuate significantly in the aggregate, across commodity groups, between depots and between customer groups. Rosenfield (Andersen Consulting 1994) notes that even good demand forecasts contain significant errors but for purposes of estimating the inventory effects of alternative logistics strategies, aggregate methods [e.g., historical demand] are effective. This study, like the DODMDS and Holmes Studies, develops an optimal strategic network and uses historical demand (albeit two years instead of one year) as a basis for analysis and conclusions.

The current effort differs from the DODMDS and Holmes studies in that it models positioning of individual line items rather than aggregated product categories. Therefore, product aggregation is not required. This study, however, utilizes demand aggregation techniques suggested by the DODMDS and Holmes Studies to reduce the scope of effort required to prepare demand-related data. The next section provides discussion and rationale for these demand aggregation techniques.

2. Studies of Civilian Distribution Networks

A considerable amount of work has been published during the last two decades on aspects of distribution system design (e.g., Kasilingham [1998], Andersen Consulting [1994], Ballou [1992] and Magee, Copacino and Rosenfield [1985]). However, little public information appears to exist on data aggregation techniques and the effects of using such techniques on results. Geoffrion and Powers [1995] comment:

> The lion's share of work in optimizing logistics networks lays in developing the necessary data...one reason for the paucity of information may be that, as a topic, data development is so burdened with application-specific details that it does not lend itself easily to research, articles, or software of general applicability. Another impediment is concern for proprietary interest.

Individually recognizing more than 700 Navy DLR customers in the positioning model suggested by this thesis appears possible but is considered too time consuming to pursue and unnecessary due to a high concentration of customers in relatively few demand locations. Therefore, this study requires a demand aggregation scheme. Bender [1985] notes:

> The most critical step in the [logistics system] analysis and design process is to determine the right level of data aggregation...Generally, the most difficult decision on level of aggregation deal with products, and with demand markets.

Ballou [1994] remarks that analysts had employed numerous schemes to group customers, including:

> ... political boundaries, Standard Metropolitan Statistical Areas, marketing territories, national geocoding systems and empirically generated maps... [but that] Research [had] not yet shown an optimal way for forming customer clusters.

However, he also suggests that clustering by zip codes is a practical way to procede and suggests a method whereby customers are initially aggregated by the first three digits of their zip codes. These clusters are then placed into ordered pairs based on geographic proximity. The ordered pair with the lowest distance between zip codes is then combined to form a new cluster and its geographic center recomputed. This process is repeated until the total number of clusters is reduced to a desirable level. Inventory positioning models typically utilize 100 to 200 customer clusters (Ballou 1994). Both the DODMDS and Holmes studies utilize zip code based customer aggregation schemes.

Aggregation, however, introduces possible errors into the analysis. Bender [1985] states: "the more aggregated the data, the greater the potential errors in analysis but the simpler it is to analyze, and the cheaper it is to assemble." Ballou [1994] defines two types of errors associated with demand aggregation: cost errors and optimality errors. Cost errors result from estimating transportation cost to aggregated demand regions rather than computing the true cost to individual customers. Optimality errors follow from "misallocating customers to source points [i.e., depots], and the resulting misallocation of source points, due to the use of clustered demand rather than individual customer demand [Ballou 1994]." Little literature appears to exist on data development. Other than Ballou [1994], we find no recent studies on aggregation effects. Earlier research [mentioned by Ballou] on cost and optimality errors includes that of House and Jamie [1985] and Current and Schilling [1987]. House and Jamie's [1985] study looked at distribution

networks for consumer products composed of up to 100 source points and 900 customer clusters found:

- Cost errors decrease as the number of demand clusters increase;
- Cost errors cannot be adequately contained with less than 100 demand clusters;
- Cost errors do not exceed 3 percent when utilizing at least 150 demand clusters; and
- As the ratio of source points to demand clusters increase, cost error increases.

Current and Schilling's [1987] study looked at distribution networks with up to ten source locations and 70 customer clusters and found:

- Optimality errors average about one and one half percent;
- Cost errors average about 15 percent;
- Optimality and cost errors decrease as the number of demand clusters increase;
- Optimality and cost errors monotonically increase with the number of sources; and
- Fewer demand clusters cause bias towards too many sources.

A 1994 study by Ballou (1994) aims at providing precise methodology and broad guidance on demand cluster formation and selection for researchers conducting similar efforts. His study analyzes a CONUS network for distributing consumer products composed of demand clusters derived from 900 three digit zip codes, up to 100 source points and surface shipment sizes between 500 and 40,000 lbs. Major findings of this research include:

- The common practice of utilizing 100 to 200 demand clusters for consumer products may not be valid for all problems because of the sensitivity of cost errors to shipment size, number of sources and maximum cluster size. 200 demand clusters appears adequate for networks with up to 25 sources. However, above 25 sources, the number of clusters should be increased substantially.

- Shipment size and the associated transportation rates affect the magnitude of cost errors;

- Controlling cluster size decreases cost errors;

- The minimum number of demand clusters should parallel the number of source points in the network; and

- Aggregating demand by proximity and controlling cluster size is a reasonable approach to any facility location problem.

Ballou notes that the results of his study generally validate the findings on cost errors from previous research conducted by House and Jamie [1985] and Current and Schilling [1987] .

All of these researchers suggest that aggregating demand by proximity causes some level of cost errors but that these errors can be reasonably controlled by considering basic guidelines for cluster formation. Ballou [1994] comments that 200 demand clusters are necessary to properly model a network of DLA's size. However, this recommendation is inapplicable to the current effort given that we model only single line items whose demand originates from at most 11 three-digit zip codes/overseas locations. Also, Ballou [1994] utilizes (continuous) rate estimating curves (derived from the surface transportation rates associated with shipments from three large common carriers) to compute transportation cost between source and demand clusters. This study, however, utilizes actual (discrete) transportation rates of commercial and government small package carriers taken from rate tables based on actual weight and point to point delivery. We find that transportation rates do not change for origin-destination five digit zip code pairs as long as the first three digits of each pair remain unchanged. For these reasons, we feel that no increase in transportation cost accuracy can be gained by increasing the number of clusters.

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III. INTEGER LINEAR PROGRAM (ILP) AND DATA

This chapter provides the ILP, discusses the data set used and details assumptions. The ILP decides optimal positioning of a single item or group of items within a distribution network. It determines the optimal strategic distribution network (i.e., decides optimal depots for a network operating over a long period of time) as opposed to a (short-term) tactical or operational plan. In this strategic network, customers are sole-sourced to a single depot for a particular item. The PTF is a sole source facility: line items stocked at the PTF cannot be obtained from any other depot. The ILP has two objective functions: minimize cost and minimize LRT. The solution to the first objective function becomes the "GOAL" (distribution budget constraint) when solving for the second objective. The ILP contains upper and lower depot throughput capacity constraints that would typically be inactive for single item studies. This model does not consider depot fixed costs or make depot closure decisions.

We make many simplifying assumptions in deriving data for the ILP to reduce the time required to collect data. This ILP does not provide an exact estimate of the cost and time associated with DLR positioning; rather, it gives valuable insight into the relationships that exist between cost, time and demand and suggests optimal solutions based on those relationships. Assumptions/limitations inherent to this study include:

Demand Location:
We assume unchanging demand locations although this study uses the actual demand from two previous years. Also, we assume demand always occurs at the customer's homeport address although it is likely that such demand may originate from deployed locations (about one quarter to one third of the time).

Transportation Modes:
The mode scheme involves only six possible modes, having at most three transportation legs. The DOD Transportation system is obviously more complex with shippers having a myriad of modes available to meet RDDs or UMMIPS standards. The mode scheme presumes only two POEs for OCONUS shipments. AMC has many more POEs; however, the selected locations appear to be the most likely utilized for Navy shipments.

DPT:

This study assumes DPT of one, two and three days for TP1, TP2 and TP3 items, respectively. In reality, local customers of a particular DD can find DPT for TP1 items available at the DD to be less than a full day (assuming they pick up the items themselves). However, as a generalization, these DPTs appear reasonable for study purposes.

LRT Standards:

This study derives demand tables (quantity of demand by location by TP) based on LRT standards from DOD Materiel Management Regulation 4140.1-R, Appendix 8 (DOD 1998). The Navy's version of LRT, taken from most recent update of NAVSUP Pub P485 (July 1999), shows different LRT standards (para 3049). We received the new information too late to factor into this thesis.

A. INTEGER LINEAR PROGRAM

Indices:

i Products (DLRs)

v Supply source (manufacturers, commercial repair depots and organic repair depots)

d Distribution depots (23 DLA depots, PTF)

p Priority (TP1, TP2, TP3)

c Customer (Aggregated customer regions)

Sets:

QUALPTF	Set of all items i that qualify for the PTF.
REPD	Set of all maintenance depot supply sources.

Data:

wt_i	Gross weight of item i (CWT per item).
$surv_i$	Survival rate (from repair, service and transportation) of item i.
$ltcap_d$	Lower throughput capacity of depot d (CWT per year).
$utcap_d$	Upper throughput capacity of depot d (CWT per year).
$cvd_{i,v,d}$	Inbound cost to deliver item i from source v to depot d:

$$= up_i \quad + \quad tcin_{i,v,d}$$

where:

up_i Cost of item i (\$ per item).

$tcin_{i,v,d}$ Cost of transporting item i from source v to depot d (\$ per item).

$vc_{i,d}$ Variable cost of processing item i through depot d (\$ per item).

$dem_{i,p,c}$ Projected annual demand for item i of priority p by customer c.

$tcout_{i,p,d,c}$ Outbound cost to deliver product i of priority p from depot d to customer c.

$t_{i,p,d,c}$ Time to process and transport item i of priority p from depot d to customer c:

$$= dpt_{i,p,d} + dtout_{i,p,d,c}$$

where:

$dpt_{i,p,d}$ Depot processing/shipment preparation time (days).

$dtout_{i,p,d,c}$ Time to transport item i of priority p from depot d to customer c (days).

GOAL Goal for aggregate annual (variable) distribution cost (\$).

Binary Variables:

k_d one, if positioning at depot d.

s_i one, if product i is sole sourced from the *PTF*.

Non-Negative Variables:

$X_{i,v,d}$ Inbound flows of product i from supplier v to depot d.

$Y_{i,p,d,c}$ Outbound flows of product i with priority p from depot d to customer c.

Formulation:

Objective functions:

$$MIN \quad \sum_{i,v,d} cvd_{i,v,d}\, X_{i,v,d} \quad + \quad \sum_{i,v,d} vc_{i,d}\, X_{i,v,d} \quad + \quad \sum_{i,p,d,c} tcout_{i,p,d,c}\, Y_{i,p,d,c}$$

$$MIN \quad \sum_{i,p,d,c} t_{i,p,d,c}\, Y_{i,p,d,c}$$

Subject to:

$$\sum_{d} Y_{i,p,d,c} \;\geq\; dem_{i,p,c} \quad , \quad \forall_{i,p,c} \tag{1}$$

$$\sum_{v} X_{i,v,d} \;\geq\; \sum_{p,c} Y_{i,p,d,c} \quad , \quad \forall_{i,d} \tag{2}$$

$$\sum_{i,v} wt_i\, X_{i,v,d} \;\leq\; utcap_d\, k_d \quad , \quad \forall_d \tag{3}$$

$$\sum_{i,v} wt_i\, X_{i,v,d} \;\geq\; ltcap_d\, k_d \quad , \quad \forall_d \tag{4}$$

$$Y_{i,p,d,c} \;\leq\; dem_{i,p,c}\, s_i \quad , \quad \forall_{i\in QUALPTF, d=PTF, p,c} \tag{5}$$

$$Y_{i,p,d,c} \;\leq\; dem_{i,p,c}(1-s_i) \quad , \quad \forall_{i\in QUALPTF, d\neq PTF, p,c} \tag{6}$$

$$\sum_{i,v,d} cvd_{i,v,d}\, X_{i,v,d} + \sum_{i,v,d} vc_{i,d}\, X_{i,v,d} + \sum_{i,p,d,c} tcout_{i,p,d,c}\, Y_{i,p,d,c} \leq GOAL \tag{7}$$

$$surv_i \sum_{v,d} X_{i,v,d} \;=\; \sum_{v\in REPD,d} X_{i,v,d} \quad , \quad \forall_i \tag{8}$$

$$s_i \in \{0,1\} \; for\; i \in QUALPTF \tag{9}$$

$$k_d \in \{0,1\} \; for\; \forall_d$$

$$X_{i,v,d} \;\geq\; 0 \quad , \quad \forall_{i,v,d}$$

$$Y_{i,p,d,c} \;\geq\; 0 \quad , \quad \forall_{i,p,d,c}$$

B. CONSTRAINT EXPLANATION

(1) Outflows must meet customer demand. (2) Flows going into depots must be greater than or equal to flows going out of depots. (3) Throughput cannot exceed throughput capacity.

(4) Minimum throughput must be observed for open depots. (5) The PTF is a sole source facility. (6) Items flowing through the PTF cannot flow through any other depot. (7) This constraint places a limit on aggregate annual distribution cost. It is used when minimizing the second objective. (8) This constraint requires sourcing from repair depots for the proportion of items that historically survive use and the repair process. (9) Binary variables and non-negativity constraints.

C. DATA CHARACTERISTICS AND ASSUMPTIONS

This section discusses the assumptions made to populate the data for the ILP.

1. Database

This section describes the representative items. This study uses a database (hereafter referred to as "the database") of 273,019 requisitions (9,724 line items) constructed in Microsoft ACCESS using Requisition File History and Demand Projections provided by NAVICP. Products in the database possess the following characteristics:

- actual demand during the period 01 October 1996 to 30 September 1998;
- projected annual demand of four or more as of 30 September 1998;
- product unit weight less than or equal to 150 pounds (lbs); and
- requisition quantity equal to one.

Only items with a unit weight less than or equal to 150 lbs are considered so that all may be eligible for stockage at the PTF; items greater than 150 lbs constitute about five percent of the items meeting other criteria. Requisition quantities greater than one are excluded to ensure shipping weight does not exceed 150 lbs but these requisitions only make up about one and one half percent of requisitions meeting all other criteria. This thesis derives demand location from the permanent address of the requisitioner, identified by the requisition's Unit Identification Code (UIC). "Demand location" refers to the UIC shipping address as listed in the Department of Defense Activity Address Code (DODAAC) database (DLA 1999c).

Cog appears to be a factor in distribution cost. Requisitions for aviation cogs ("aviation requisitions/items") in the database constitute 64 percent of requisitions and 74 percent of demand weight as shown in Table 3.1. These DLRs have an average unit weight of 20.9 lbs whereas non-aviation DLRs ("non-aviation requisitions/items") average 13.5 lbs. Based on these results, we expect that aviation items are heavier on average than non-aviation items and therefore more expensive to distribute. Aviation requisitions generally have higher TP than non-aviation requisitions as shown in Table 3.2. This suggests that aviation items also are more expensive to transport as they require faster modes of transportation. For these reasons, cog appears to be an appropriate criteria to use in the test set selection.

Cog	% of Total Reqns	% of Total Wt (Lbs)
7E	1.63	1.29
7G	5.70	2.55
7H	28.20	22.39
7R	64.39	73.70
7Z	0.07	0.06
Total	100.00	100.00

Table 3.1: Breakdown of Requisition Database By Cog

This table presents a breakdown of requisitions by cog derived from the database. This database contains 273,019 requisitions with a total weight of 4,974,381 pounds.

Unit weight does not appear to be a factor in demand location. The top 14 demand locations make up 89 percent of wholesale demand and are the basis of this analysis. Analysis of demand weight by location by Cog (Aviation vs. Non-Aviation) for seven unit weight categories (Table 3.3) shows little difference between overall demand percentage by location and the demand by individual weight categories for each location, as shown in the Appendix, Table 1.

Cog(s)	TP(s)	Percentage of Demand Wt
All	1	56.9
	2 and 3	43.1
	Total	100.0
Aviation	1	69.6
	2 and 3	30.4
	Total	100.0
Non-Aviation	1	21.3
	2 and 3	79.7
	Total	100.0

Table 3.2: Transportation Priority by Cog

This table presents a breakdown by cog of the percent of database demand weight by TP. It implies that aviation items have higher TP than non-aviation items.

1 to 2 lbs
2 to 5 lbs
5 to 10 lbs
10 to 20 lbs
20 to 50 lbs
50 to 100 lbs
100 to 150 lbs

Table 3.3: Weight Categories for Testing Geographic Distribution of Unit Weights

This table presents the breakdown of DLR unit weight used to analyze the top 14 demand locations.

In most cases, individual weight category values cluster reasonably close to the aggregate percentage of total demand weight by location and have standard deviations less than 25 percent of this value. For this reason, unit weight does not appear to be a factor in demand location. For the test set selection, products are arbitrarily divided into three weight categories: 0 to 50 Pounds, 50 to 100 Pounds and 100 to 150 pounds. Table 3.4 presents a breakdown of the total demand weight for these three weight categories.

Location	0 to 50 lbs	% of Total	50 to 100 lbs	% of Total	100 to 150 lbs	% of Total	Total Weight	% of Total
San Diego	454,091	18.9	309,248	21.3	150,529	13.5	913,869	18.4
Jacksonville	354,772	17.1	256,404	17.6	239,973	21.5	908,147	18.3
Norfolk	411,769	14.8	190,354	13.1	122,717	11.0	667,844	13.4
Whidbey Island	149,704	6.2	95,110	6.5	71,181	6.4	315,486	6.3
Bangor	149,704	6.2	78,378	5.4	57,024	5.1	285,106	5.7
Pearl Harbor	148,374	6.2	80,489	5.5	55,520	5.0	284,383	5.7
Yokosuka	86,490	3.6	53,813	3.7	34,875	3.1	175,178	3.5
Okinawa	69,950	2.9	40,240	2.8	53,971	4.8	164,161	3.3
Lemoore	73,053	3.0	35,462	2.4	51,326	4.6	159,841	3.2
Misawa	55,875	2.3	49,533	3.4	52,488	4.7	157,896	3.2
Oceana	62,247	2.6	62,744	4.3	12,279	1.1	137,270	2.8
Iwakuni	60,149	2.5	30,285	2.1	36,834	3.3	127,268	2.6
Diego Garcia	26,749	1.1	20,327	1.4	33,828	3.0	80,904	1.6
Atsugi	40,802	1.7	15,175	1.0	15,394	1.4	71,371	1.4
Others	261,635	10.9	137,407	9.4	126,617	11.4	525,660	10.6
Totals	2,404,855	100.0	1,454,969	100.0	114,556	100.0	4,974,387	100.0

Table 3.4: Total Demand Weight for Test Set Unit Weight Categories (Lbs)

This table presents a breakdown of the demand weight for the top 14 demand locations by unit weight categories 0 to 50 lbs, 50 to 100 lbs and 100 to 150 lbs.

FSG appears to be a factor in the demand location. Database DLRs break down into 192 different FSCs composed of 32 FSGs and 22 product classes. FSGs represent major materiel categories and appear to be the most appropriate of these three categories (FSCs, FSGs and product classes) for further analysis. The top 11 FSGs constitute 91 percent of requisitions and 89 percent of requisition weight. Table 3.5 presents a description and summary statistics on these FSGs. The large differences in average unit weight imply that average distribution cost of some groups is higher than others (e.g., FSGs 15 and 26). FSGs are closely related to cog: certain FSGs such as 15 and 16 clearly describe aviation items and are almost entirely populated by aviation cogs. Table 3.6 provides a breakout of these FSGs by cog. Aviation items comprise 64 percent of database requisitions. If FSG has no impact on demand, then the percent of aviation requisitions by FSG should be fairly close to the overall proportion (64 percent) in the database.

However, the database does not support this presumption, as shown in Table 3.6. Therefore, we feel a representative sample of DLRs should include items from each FSG.

FSG	Description	Dem Qty	% of Total	Dem Wt (lbs)	% of Total	Ag Wt (lbs)	Std Dev Wt (lbs)
16	Aircraft Comp & Access	34,184	12.5	841,757	16.9	24.62	32.48
66	Instruments & Lab Equip	36,571	13.4	548,582	11.0	15.00	23.44
61	Elec Wire & Pwr & Dist	21,381	7.8	514,223	10.3	24.05	32.43
26	Tires	8,948	3.3	447,602	9.0	50.02	37.04
58	Communications Equip	38,418	14.1	447,059	9.0	11.64	18.75
28	Engines, Turb & Comp	19,324	7.1	434,532	8.7	22.49	32.65
59	Elec & Electronic Equip / Components	52,779	19.3	401,247	8.1	7.6	15.95
29	Engine Accessories	17,001	6.2	285,174	5.7	16.77	22.34
15	Aircraft / Airframe Structural Components	3,735	1.4	212,326	4.3	56.85	50.35
43	Pumps & Compressors	4,954	1.8	163,901	3.3	33.08	35.34
48	Valves	11,335	4.2	141,103	2.8	12.45	21.91
	Subtotal	248,630	91.1	4,437,506	89.2		
	Other FSGs	24,389	8.9	536,875	10.8		
	Total	273,019	100.0	4,974,381	100.0		

Table 3.5: Top 11 FSGs by Demand Weight

This table presents those database FSGs with a two-year demand exceeding 100,000 lbs and includes related statistics.

FSG	Description	7R Cog	N7R Cog	% 7R Cog	% N7R Cog
15	Aircraft /Airframe Structural Components	175	0	100.0	0.0
16	Aircraft Components & Accessories	1,067	3	99.7	0.3
26	Tires	8,948	0	100.0	0.0
28	Engines, Turb & Comp	12,609	6,715	65.3	34.7
29	Engine Accessories	13,841	3,160	81.4	18.6
43	Pumps & Compressors	3,048	1,906	61.5	38.5
48	Valves	6,304	5,031	55.6	44.4
58	Communications Equip	21,137	17,281	55.0	45.0
59	Elec & Electronic Equip / Components	19,635	33,144	31.2	62.8
61	Elec Wire & Pwr & Dist	10,958	10,423	51.3	48.7
66	Instruments & Lab Equip	28,669	7,902	78.4	21.6

Table 3.6: Requisition Quantity by FSG by Cog

This table presents FSGs broken out by database requisition quantity into aviation and non-aviation components.

2. Customers

We use customer location to construct both outbound (depot to customer) transportation cost ("tcout") and time ("dtout") tables for the model. Individual customer demand is treated collectively using geographic aggregation. The database contains demand for 722 individual customers (UICs). This study aggregates CONUS customers into geographic clusters using the first three digits of their shipping zip code and aggregates OCONUS customers to the closest likely Aerial Port of Debarkation (APOD). This aggregation creates 96 customer regions worldwide. Predictably, most of the demand (about 90 percent) is concentrated in the homeports of ships, submarines and aircraft (just 14 locations), as shown in Table 3.4. Non-Aviation demand is more concentrated than aviation demand: the top 10 non-aviation locations make up 90.0 percent of total non-aviation demand while the top 10 aviation locations comprise 81.5 percent of total aviation demand.

In this study, we treat demand as originating from the customer's homeport. In reality, most of these customers deploy and therefore, some portion of their demand takes place somewhere else in the world. 73,895 (27 percent) of the 273,019 test set requisitions have a document identifier indicating the requisition requires overseas shipment. This proportion appears reasonable given a typical operational tempo of about one six-month deployment every 18 to 24 months. Requisitions do not provide the location of the customer at the time of demand. While in homeport, customers typically route requisitions into the supply system through the closest FISC. Requisitioning rules defined in NAVSUP Pub 485, Afloat Supply Procedures, give requisition routing instructions for deployed units. For example, a San Diego-based ship normally routes its requisitions to FISC San Diego; however, once deployed, requisition routing changes to FISC Pearl Harbor Hawaii (if it stops there) and then to FISC Yokosuka Japan once it comes under operational control of Seventh Fleet. Atlantic Fleet ships (e.g., Norfolk) do not have an overseas FISC to utilize, and all of their requisitions continue to be routed through FISC Norfolk while deployed. The design of a distribution network is heavily influenced by customer

location but since actual demand locations cannot be reliably identified and depot locations are fixed, we believe the most reasonable assumption for customer location is the unit's homeport, where it resides and receives supplies 70 percent of the time.

Test set items have demand in 40 of the 96 customer regions found in the database, including the top 14 regions described previously. Table 2 in the Appendix presents a summary of these demand regions.

3. Vendors

This study uses vendor locations to construct inbound (vendor to depot) transportation cost ("tcin") tables in the model. For this thesis, "vendor" refers to both commercial source and repair depot.

Two potential sources of supply exist in the ILP for each product: DOP for repaired items and a single commercial source for each item's new procurement. We use source locations to construct the inbound transportation cost tables for the model. This study derives test set DLR DOPs from data provided by NAVICP. The ILP determines the proportion of items originating from new procurement using a survival rate coefficient (a number between 0 and 1). This coefficient represents the aggregate probability an item survives both use and transportation (Carcass Return Rate (CRR)) and the repair process (Repair Survival Rate (RSR)). UICP maintains CRRs and RSRs for all DLRs. We calculate the survival rate coefficient by multiplying CRR by RSR. The percent of new items procured is, therefore, 1 - (CRR*RSR).

4. Storage Depots

This study uses storage depot location in the construction of tcin, tcout and dtout data, deriving US locations from the depots' zip codes and overseas locations using the closest APOD served by the Air Mobility Command (AMC). Ramstein Air Force Base Germany and Yokota Air Force Base Japan represent APODs used in the model for DDs in Germerscheim, Germany and Yokosuka Japan, respectively. AMC also uses these APODs as hubs to serve other theatre bases. Although this data does not capture the time or expense of ground transportation between

the overseas DDs and APODs, we believe the data reflects the most expensive part (in terms of time and dollars) of the overseas movement and is adequate for modeling purposes.

The study derives upper DD throughput capacity ("utcap") in units of hundred lbs per year from the 1995 Defense Distribution System study (DDS study) (KPMG Peat Marwick Limited Partnership 1995). Lower throughput capacity ("ltcap") is arbitrarily set at 0 for all DDs because the ILP does not consider depot fixed costs or make depot closure decisions. Table 3.7 presents estimated upper throughput capacities used as data for the ILP.

Depot variable costs ("vc") represent the costs of processing materiel into and out of depots and are analogous to issuing and receiving costs. This thesis uses the DDS study to derive DD vc estimates. Since these are estimates, no attempt is made to convert these costs to current year dollars. The DDS study excludes five depots examined in the current effort (Letterkenney, McClellan, Yokosuka, Germersheim and Pearl Harbor). This thesis estimates the associated vc for these depots using the average vc of the other DDs and estimates PTF vc using the actual rates charged to the government for issuing and receiving. Table 3.7 details vc by depot. The DDS study considers fixed costs of depot operations to be "the cost incurred by keeping a specific distribution center open" and treats storage cost as a component of fixed costs (Peat Marwick 1995). The current effort does not consider fixed costs of depot operations and therefore, depot storage cost is not modeled.

This study arbitrarily sets DPT (for all depots) to 1, 2 and 3 days for TP1, 2 and 3 materiel, respectively. An analysis of DPT associated with 271,000 DLR shipments made during 1997 and 1998 reveal numerous depots where higher numbered priority items on average are processed slower than those with lower numbered priorities, that have significant outliers and that have high standard deviations. Therefore, this study ignores historical DPT in favor of a DPT scheme where average DPT decreases as TP increases. This scheme also assumes negligible transportation delays. It uses lower DPTs by TP than found in an analysis of actual DPTs from 1997 and 1998 DLR shipments; however, we believe the actual DPT data contains too

Depot	Variable Unit Cost per 100 lbs		Throughput Capacity
	Bin	Bulk	Hundred lbs per Year
Susquehanna PA	58.710	9.160	3,339,841
Letterkenny PA	81.626*	10.245*	600,603***
Tobyhanna PA	83.230	9.280	532,609
Richmond VA	83.130	9.180	1,352,128
Norfolk VA	89.050	15.100	2,861,776
Cherry Point NC	83.510	9.560	294,023
Warner Robins GA	83.300	9.350	1,347,923
Albany GA	83.180	9.230	364,419
Jacksonville FL	88.220	14.270	883,439
Anniston AL	83.090	9.140	585,122
PTF Memphis TN	17.130**	17.130**	Unlimited
Columbus OH	83.170	9.220	2,355,879
Oklahoma City OK	83.690	9.740	1,973,722
Red River TX	83.230	9.280	1,263,908
Corpus Christi TX	88.430	14.480	241,767
Hill UT	83.140	9.190	1,137,212
San Diego CA	83.320	9.370	2,329,035
Barstow CA	83.370	9.420	156,139
San Joaquin CA	58.740	9.190	4,380,792
McClellan CA	81.626*	10.245	667,346***
Puget Sound WA	83.170	9.220	313,843
Yokosuka JA	81.626*	10.245	60,166***
Germerscheim GE	81.626*	10.245	372,713***
Pearl Harbor HI	81.626*	10.245	285,487***

Table 3.7 : Depot Variable Costs and Throughput Capacity

This table presents estimated variable costs calculated by Peat Marwick in the 1995 DDS Study using FY96 DLA Management Information System data by depot for bin and bulk items. Bin items weigh less than 35 pounds and have no dimension greater than 18 inches; bulk items weigh more than 35 pounds and /or have a dimension greater than 18 inches (Gotwalt 1998). The DDS Study calculates maximum throughput capacity by depot based on the amount of throughput (lbs) processed in an eight hour day times 250 work days per year times 85 percent (KPMG Peat Marwick 1995). * represents estimates we made for depots not included in the DDS Study based on the average of all other DDs in the study. ** This is a per unit cost and does not depend on weight. Based on FY99 Contract Rates of $19.56 for receipts and $10.61 for issues. Receipt cost is the same per line item regardless of quantity received (i.e., $19.56 is receipt cost for 1 unit or 1000 units of a single DLR line item). Receipt cost per item assumes one receipt for every three issues (i.e., average units received of particular line item is three) based on a 1997 NAVTRANS study of returns from commercial repair (Emerick 1998). *** represents estimates made by this study for depots not included in the DDS study: calculated as the average ratio of depot throughput capacity (lbs) to physical capacity (cubic ft) (for depots in the DDS study) times depot physical capacity. This study obtains physical capacities from DLA Storage Capacity Reports (DLA 1998b).

many factors outside of DPT (such as transportation hold times, input errors, etc.) to find the true structural differences between depots. Tables 3.8, 3.9 and Figure 3.1 present the results of the DPT analysis.

DPT Statistics Associated with DLR Shipments to 22 DDs in 1997 and 1998**				
TP(s)	**Avg DPT**	**Std Dev DPT**	**Max DPT**	**Min DPT**
All	3.017	18.595	3784.5	0.0
All*	4.842	23.367	3784.5	0.1
1	2.688	22.531	3784.5	0.0
1*	5.713	32.582	3784.5	0.1
2	3.246	14.872	868.3	0.0
2*	4.422	17.207	868.3	0.1
3	2.920	17.718	735.9	0.0
3*	4.484	21.797	735.9	0.1

Table 3.8: Summary Analysis of 1997 and 1998 DPT associated with DLR Shipments

This table presents analysis of DPT associated with 271,807 DLR shipments made from August 1997 to September 1998. Source data comes from an LRT database provided by NAVICP, originally obtained from DAAS. 102,423 of these shipments have a recorded DPT = 0. We believe these zero entries are erroneous reflecting depot input errors, based on conversations with NAVICP (Diehl 1999)); however, these entries likely reflect DPTs of less than one day (Diehl 1999). Therefore, true average DPT probably lies somewhere between the averages shown in the aggregate and for each TP. Statistics are based on all DLR shipments in the database. * shows statistics for shipments with DPT greater than zero. Only about 22,000 requisitions (less than 10 percent) have corresponding RDDs in the LRT database. RDD is normally required to determine TP. Therefore, the study ignores these RDDs and arbitrarily divides the requisitions into TP1, TP2 and TP3 categories based solely on requisition priorities 01 to 03, 04 to 08 and 09 to 16, respectively (which should roughly approximate the actual division). ** No Navy DLRs currently stocked at the DD in Germany.

Depot	TP1		TP2		TP3	
	Avg DPT	Std Dev	Avg DPT	Std Dev	Avg DPT	Std Dev
Susquehanna PA	3.422	13.141	2.133	7.347	2.701	3.052
Letterkenney PA	3.729	6.175	0.853	1.288	0.5	n/a
Tobyhanna PA	6.434	22.158	11.785	42.262	3.136	11.737
Richmond VA	9.427	22.880	6.814	23.127	2.751	4.234
Norfolk VA	1.569	32.725	1.993	10.692	2.633	14.649
Cherry Point NC	1.913	10.705	4.188	9.364	9.083	19.705
Warner Robins GA	3.629	27.650	18.669	60.897	3.225	10.806
Albany GA	0.500	0.505	1.467	1.553	24.683	54.710
Jacksonville FL	2.792	13.065	2.461	12.103	5.012	13.785
Anniston AL	N/A	N/A	0.8	n/a	0.4	n/a
Columbus OH	2.722	21.294	3.625	11.286	2.653	4.782
Oklahoma City OK	6.201	32.737	6.904	35.643	1.133	1.600
Red River TX	3.386	14.213	1.977	5.904	1.770	1.329
Corpus Christi TX	6.106	27.649	6.720	29.185	7.711	23.704
Hill UT	4.745	11.846	6.358	15.526	5.212	16.278
San Diego CA	1.948	11.280	2.256	10.255	4.543	36.423
Barstow CA	1.780	1.320	2.682	4.306	2.775	7.252
San Joaquin CA	2.411	6.464	2.402	11.620	8.625	58.154
McClellan CA	2.871	11.438	40.251	103.484	1.262	1.016
Puget Sound WA	0.988	6.233	2.277	7.775	3.336	8.971
Yokosuka JA	3.499	11.405	8.584	15.670	52.667	104.379
Pearl Harbor HI	2.432	6.680	6.090	9.790	9.344	16.023

Table 3.9: DPT Statistics by Depot

This table presents summary statistics by depot for all issues in the LRT database using the same assumptions mentioned for Table 3.8. 90 percent of issues originate from DDs co-located with FISCs and near Navy activities (Cherry Point NC and Corpus Christi TX).

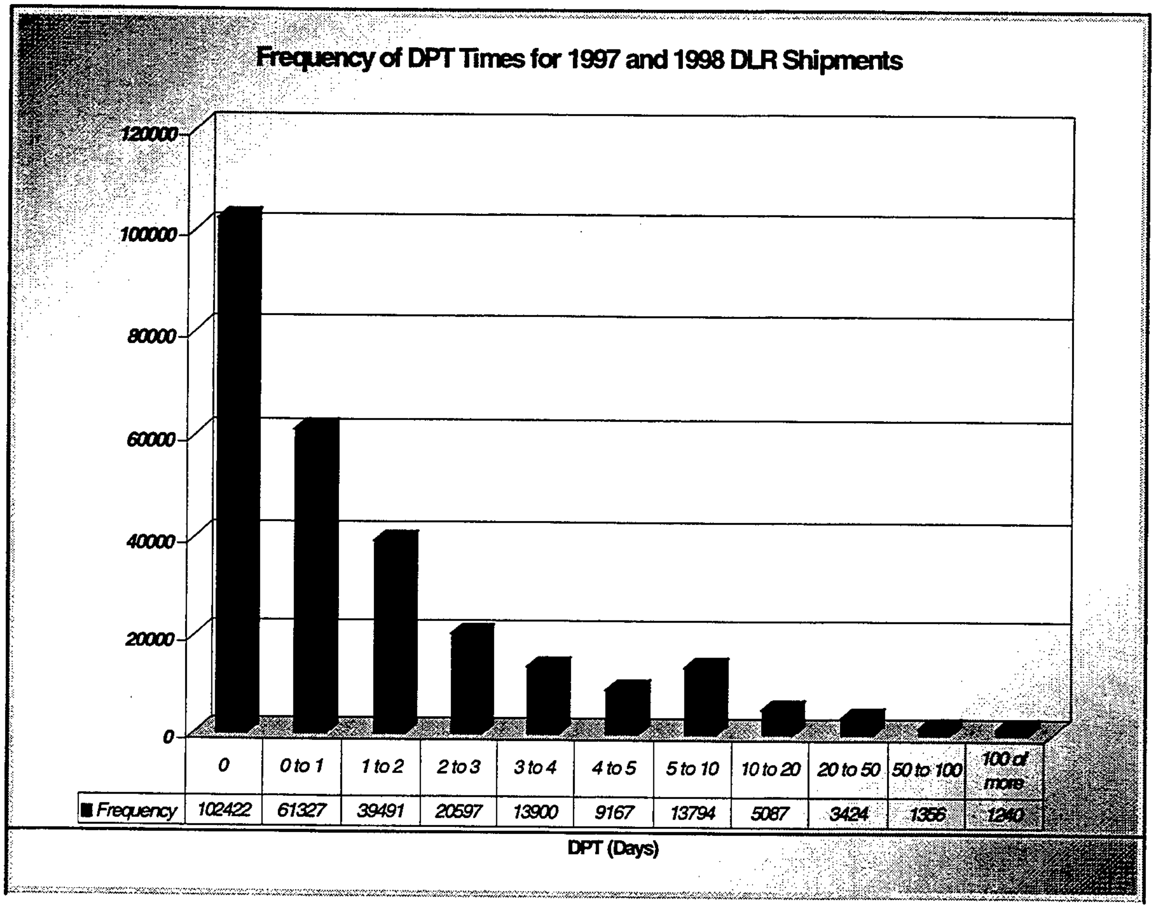

Figure 3.1: Frequency of DPT Times for DLRs Shipped in 1997 and 1998

This chart presents the frequency of DPT times for DLRs shipped from August 1997 to September 1998, taken from the LRT database provided to NAVICP by DAAS. More than 100,000 DPTs in this database equal zero. As described in Table 3.8, the zero entries are erroneous and probably represent DPTs of the adjacent (0 to 1) bin.

5. Transportation Modes, Times and Costs

Transportation rates, times and costs for the myriad of modes utilized by DOD shippers are not readily available. Table 1.3 implies, however, that DLRs generally transit in faster (and more expensive) modes than other items in the supply system. Although this table only captures the last mode, more than 55 percent of items moved via an air mode of transportation and almost

none via ocean surface transit (Boylan 1999). Therefore, this study uses a simplified transportation mode scheme composed of six possible modes, including four CONUS (three air, one surface) and two OCONUS (air) modes, to determine inbound and outbound transportation cost and outbound transportation time.

In this model, DDs make CONUS deliveries via one of three United Parcel Service (UPS) modes: "Overnight Delivery" (most expensive and fastest) , "Third Day Air" and "Ground" (least expensive and generally the slowest). TP1 materiel transits via the "Overnight Delivery" mode unless the Ground mode can deliver the item in one day. TP2 materiel transits via "Third Day Air" unless the ground mode is as fast or faster. TP3 materiel transits via ground mode. The fourth CONUS mode is FedEx overnight delivery: items positioned at the PTF use this mode exclusively.

According to NAVTRANS, OCONUS DLR shipments currently move mainly via AMC (Boylan 1999). Therefore, this model uses two OCONUS Modes: AMC and FedEx. AMC transports DLRs between CONUS POEs and OCONUS PODs and vice versa and between OCONUS locations. Items from CONUS DDs transit via UPS to one of two AMC PODs, Norfolk Naval Air Station (NAS Norfolk) or Travis Air Force Base (Travis AFB), depending on proximity of the POE to the overseas POD. NAS Norfolk regularly services locations throughout Northern and Southern Europe. Travis AFB regularly services Hawaii, the Far East and South West Asia. For purposes of this study (LRT and transportation cost), the OCONUS mode effectively ends when the materiel reaches the in-theater POD.

This study derives outbound transit times (dtout) using the following simplifying assumptions:

- DPT includes transportation wait time;

- UPS picks up daily from the depot location as part of regularly scheduled service and pick ups occur as soon as DPT ends;

- UPS Overnight Delivery requires one day of transit time;

- UPS Third Day Delivery requires three days of transit time;

- UPS ground deliveries are made within the time specified (one to six days) by UPS for the origin to destination zip code pair at www.UPS.com.

- Including DPT, PTF CONUS deliveries are made within 24 hours;

- Including DPT, PTF OCONUS deliveries are made within 48 hours to the closest aerial POD:

- Items shipped UPS to NAS Norfolk or Travis AFB for further transfer to AMC are shipped piece by piece and not consolidated with other shipments (i.e., no delays due to shipments being consolidated at the DD); and

- Items shipped through AMC experience average aerial port holding times (APHT), transit times and aerial POD times (AMC 1999a); and

- FedEx service is not available to Diego Garcia: DDs ship items (bound for Diego Garcia) to Japan (using FedEx) for further transfer by AMC.

This study uses transportation cost estimates from four sources: UPS published rates, PTF contract rates (CONUS), FedEx World Wide Express (WWX) contract rates and U.S. DOD Airlift Rates. We derive rates for the three UPS modes using the Quick Rate Calculator reference www.UPS.com (UPS 1999) and the following inputs:

- Origin zip code;
- Destination zip code;
- Weight;

- Dimensions are not required but may effect cost. This study assumes no increase in cost due to product dimensions;
- Specification of regular scheduled pickup from a business address; and
- Specification of own packaging.

PTF transportation rates apply to destinations in all 50 states and Puerto Rico. These rates differ only by weight and are not dependent on distance traveled from the PTF. These rates range from $3.50 for a one pound item to $104.50 for a 150 pound item. OCONUS Transportation by FedEx occurs through AMC's World Wide Express (WWX) contract. We obtained WWX rates using a WWX Price Estimator downloaded from www.AMC.af.mil (1999b). This study uses Fiscal Year 1999 DOD Airlift Rate Tables to determine AMC Transport Costs (DOD 1998). These tables list transportation costs in cents per pound between various CONUS POEs and Foreign PODs. All

DOD cargo shipments are subject to a five dollar minimum charge per line item. AMC may assess charges by pound or cube but this study assumes assessment by weight (i.e., the item weighs out before it cubes out). Airlift Rates also include price breaks for shipments in excess of 439 lbs, 1,099 lbs, and 2,199 lbs. This study makes the simplifying assumption that the rate charged is always the highest rate because of lack of consolidated overseas shipments and a maximum product unit weight of 150 lbs.

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IV. COMPUTATIONAL EXPERIENCE

This chapter describes the computer runs and details testing methodology, network variants, items tested and solutions obtained using the ILP.

A. COMPUTER RUNS AND TESTING METHODOLOGY

The ILP is run on a Pentium II personal computer operating at 333 megahertz with 64 megabytes of RAM. Generation and solution times are generally less than five seconds for each run.

For each test set line item, the study uses the ILP to determine the inventory positioning scheme that minimizes LRT for a given distribution budget. We consider two budget levels: "Min Cost" and "Min LRT." Min Cost is the minimum budget ("GOAL") required to satisfy all demand at some LRT level. Min LRT is the minimum budget required to find the lowest LRT solution. We find the minimum LRT for various budgets. First, we solve the model for the first objective function (sum of tcin, tcout and vc) to determine the minimum distribution budget required to satisfy all demands. We then use this solution as the distribution cost constraint ("GOAL") for the second objective function (sum of LRTs). The solution to this second objective function represents the minimum LRT solution at the lowest budget. The minimum LRT solution may occur at the PTF (a sole source facility). For those cases where it does not, we successively increase the GOAL and rerun the ILP until the PTF becomes the solution or it becomes obvious that the PTF is not the minimum LRT solution.

B. NETWORK VARIANTS

This study examines single line item positioning within seven networks ranging in size from three to 24 depots (hereafter referred to as numbered below):

1) 24 depots: all DD's in the DLA network plus the PTF;
2) 9 depots: eight DDs co-located with Navy activities plus the PTF;
3) 8 depots : eight DDs co-located with Navy activities;
4) 7 depots: six DDs co-located with Navy FISCs plus the PTF;
5) 6 depots: six DDs co-located with Navy FISCs;

6) 18 depots: 17 DDs plus the PTF (no DDs co-located with FISCs); and
7) 3 depots: two DDs (DLA Primary Distribution Sites (PDS)) plus the PTF.

These variants implicitly consider the following questions:

- What network configuration minimizes LRT for given cost and capacity constraints?

- Should wholesale inventory be positioned at DDs not co-located with FISCs?

- How does deleting DD's co-located with FISCs affect LRT?

- What are appropriate characteristics for inventory positioned at the PTF?

- How does increased utilization of the PTF affect LRT? cost?

C. REPRESENTATIVE ITEMS

This thesis analyzes the positioning of 57 representative DLRs (the "test set") selected from the database described in Chapter III. As mentioned previously, we select test set items based on cog (aviation versus non-aviation), FSG (top 11 by demand weight) and weight Category (0 to 50 lbs, 50 to 100 lbs, 100 to 150 lbs). The test set is composed of one item from each cog/FSG/weight category combination except in two cases where such combinations do not exist: non-aviation items do not populate FSGs 15 or 26. We select items for the test set by:

- determining the actual unit weights populating each FSG/cog combination;
- arbitrarily selecting one weight within each weight category that appears to have relatively close matches (within ten percent) in each FSG/Cog combination; and
- selecting the first item shown in the database at that weight.

This study uses test set unit weights of 4 lbs, 75 lbs and 125 lbs. These weights are the basis for variable cost and transportation cost calculations. Some FSG/Cog combinations did not contain unit weights within ten percent of the selected unit weights:

FSG	Cog	Weight(s)
16	N7R	75, 125
48	7R	125.

For these cases, the study arbitrarily draws items with the closest weight and treats them as if they are the test set weight. This study selects only one weight in each weight category to reduce the

extensive compilation effort required to build associated transportation cost and variable cost tables. Table 3 in the Appendix presents a complete description of test set items. Tables 4.1 and 4.2 presents summaries of test set product characteristics.

Cog	Nr of Lis	Total DEM Qty	Mean DEM Qty per LI	Total DEM Wt (lbs)	Mean DEM Wt per LI (lbs)	Nr Demand Regions
7R	32	2,544	79.5	117,414	3,669.2	34
N7R	25	587	23.5	36,665	1,466.6	21
Total	57	3,131	54.9	154,079	2,703.1	40*

Table 4.1: Test Set Demand Characteristics by Cog

This table presents test set demand characteristics by cog. "LI" refers to line items. * Test set demand arises from 40 aggregated customer regions. This table is based on Fiscal Year 1997 and 1998 demand history.

FSG	Number of LIs	Total DEM Qty	Mean Dem Qty per LI	Total DEM WT (Lbs)	Mean DEM Wt per LI (lbs)	Number of Demand Regions
15	3	15	5.0	1,141	380.3	7
16	4	27	6.8	847	211.8	7
26	3	1,979	659.7	86,359	28,786.3	19
28	6	67	11.2	3,962	660.3	12
29	6	239	39.8	7,674	1,279.0	18
43	6	196	32.7	10,194	1,699.0	13
48	5	66	13.2	3,341	668.2	12
58	6	124	20.7	6,074	1,012.3	18
59	6	98	16.3	5,394	899.0	11
61	6	212	35.3	20,175	3,362.5	25
66	6	108	18.0	8,918	1,486.3	17
All	57	3,131	54.9	154,079	2,703.1	40*

Table 4.2: Test Set Demand Characteristics by FSG

This table presents test set demand characteristics by FSG. "LI" refers to line items. * As noted in previous table, except by FSG. This table is based on Fiscal Year 1997 and 1998 demand history.

D. RESULTS

This section provides rationale and background for the results presentation and includes individual and comparative optimization results for the seven network permutations. We also exploit these results to explore PTF item characteristics and the impact of deployed demand.

1. Results Presentation

Summary results represent statistics associated with the solutions to all 57 test set item ILPs (399 ILPs (57 products times 7 networks) for both Min Cost and Min LRT). These solutions represent a composite of the results associated with all test set items. A brief definition of unique terms used to express aggregated statistical results follow:

- <u>mean cost:</u>
  average distribution cost (tcin plus vc plus tcout in dollars per lb) of all line items in the test set (not weighted for demand quantity);

- <u>weighted mean cost (Wtd Mean Cost)</u>:
  average distribution cost (dollars per lb) for all test set items weighted by the number of units of demand in each line item;

- <u>weighted standard deviation cost (Wtd Std Dev Cost)</u>:
  standard deviation calculated using the weighted mean cost as the mean;

- <u>mean LRT</u>:
  average LRT (days) of all line items in the test set (not weighted for demand quantity);

- <u>weighted mean LRT (Wtd mean LRT)</u>:
  average LRT (days) for all line items in the test set weighted for demand quantity; and

- <u>weighted standard deviation LRT (Wtd Std Dev LRT)</u>:
  standard deviation calculated using weighted mean LRT as the mean.

2. Min Cost Solutions

Table 4.3 presents a summary by network of test set mean cost and LRT at Min Cost. These results suggest several useful insights (note all numerical comparisons are based on Wtd Mean Cost and Wtd Mean LRT):

- <u>Distribution costs increase as depots are deleted from the network</u>:

Average distribution costs rise 11 percent as the number of depots drop from 24 to 3. Deletion of depots increases the average distance (and associated transportation costs) between suppliers and

depots, and depots and customers. These costs rise even more rapidly when the PTF is not part of the network (NW3, NW5).

- The PTF holds down the rate at which distribution costs rise as DDs are deleted:

NWs 3 and 5 consist of (8) Navy co-located and (6) FISC co-located DDs, respectively. NWs 2 and 4 are equivalent but also include the PTF. The latter NWs have average costs about 12 percent lower than the former suggesting although costs rise as depots are deleted, the PTF holds down the rate of increase.

- Without the PTF, LRT increases at a higher rate as depots are removed from the network:

The PTF generally provides the best LRT solution except in those cases where TP1 demand can be satisfied by a depot co-located with a customer. NWs 2 and 4 (containing the PTF) have approximately 30 percent lower mean LRTs than NWs 3 and 5.

- Positioning only at Navy co-located Depots does not provide the lowest cost or LRT:

NWs 2 through 5 contain only DDs that are co-located with Navy sites. NW1, however, has marginally lower cost and clearly lower average LRT than all solutions from NW2 through 5 (and including NWs 6 and 7).

- Deletion of co-located DDs causes distribution costs to rise; however, LRT barely changes:

If DLA decides to close Navy co-located DDs (a NW2 or 4 scenario) in favor of the remaining depots in the NW (a NW6 or 7 scenario), average distribution costs rise about 11 percent; however, average LRT barely changes (rising about 5 percent) reflecting the dampening effect of the PTF on average LRT.

	NW1	**NW2**	**NW3***	**NW4**	**NW5***	**NW6**	**NW7**
Number of Depots	**24**	**9**	**8**	**7**	**6**	**18**	**3**
Mean Cost	1.54	1.55	1.64	1.57	1.69	2.06	2.57
Median Cost	1.48	1.46	1.48	1.46	1.50	1.63	1.63
Wtd Mean Cost	1.97	1.98	2.22	1.98	2.23	2.11	2.19
Wtd Std Dev Cost	0.89	0.91	1.06	0.89	1.02	1.26	1.80
Mean LRT	2.20	2.25	3.07	2.27	3.13	2.23	2.17
Median LRT	1.60	1.62	2.64	1.62	2.67	1.51	1.40
Wtd Mean LRT	3.24	3.47	4.71	3.34	4.58	3.58	3.60
Wtd Std Dev LRT	1.70	1.83	2.41	1.74	2.30	2.10	2.13

Table 4.3 : Summary of Min Cost Results by Network

This table presents summarized results derived by solving all test set items for Min Cost. * indicates networks that do not contain the PTF.

3. Min LRT Solutions

Table 4.4 presents a summary by network of test set mean cost and LRT at Min LRT. This analysis includes all test set products including those that are never feasible at the PTF. Because the PTF is a sole source facility, once the distribution budget rises to the point where the PTF is the optimal solution, no other depots in the network are utilized. Therefore, the test set statistics presented in Table 4.4 should be the same across all networks. The minor differences shown between cost and LRT statistics for NW1 to NW5 reflect the effect of line items that are never feasible at the PTF (included at their Min Cost solutions). All products have PTF feasibility in NW6 and NW7 scenarios, and therefore, these scenarios have test set statistics that only reflect Min LRT solutions at the PTF.

	NW1	**NW2**	**NW3***	**NW4**	**NW5***	**NW6**	**NW7**
Number of Depots	**24**	**9**	**8**	**7**	**6**	**18**	**3**
Mean Cost	3.23	3.26	N/A	3.15	N/A	3.18	3.18
Median Cost	1.66	1.66	N/A	1.63	N/A	1.63	1.63
Wtd Mean Cost	2.28	2.27	N/A	2.28	N/A	2.30	2.30
Wtd Std Dev Cost	1.32	1.32	N/A	1.31	N/A	2.51	2.51
Mean LRT	1.32	1.39	N/A	1.38	N/A	1.31	1.31
Median LRT	1.25	1.26	N/A	1.27	N/A	1.21	1.21
Wtd Mean LRT	1.70	1.72	N/A	1.71	N/A	1.70	1.70
Wtd Std Dev LRT	0.33	0.34	N/A	0.34	N/A	0.55	0.55

Table 4.4: Summary of Min LRT Results by Network

This table presents summarized results derived by solving all test set items for Min LRT.
* indicates networks that do not contain the PTF.

4. Comparison of Min Cost and Min LRT Solutions

Table 4.5 provides a comparison of the differences between aggregate solutions at Min Cost and Min LRT for all network permutations. These statistics imply (all numerical comparisons based on Wtd Mean Cost and Wtd Mean LRT):

- As DDs in the NW decrease, their relative cost advantage over the PTF also decreases:

Network 1 has the most depots and the lowest average distribution cost. It's average distribution cost is 15.5 percent higher at Min LRT than at the Min Cost (although 35 percent of Min Cost solutions occur at Min LRT). This cost difference declines to about nine percent in NW6 and five percent in NW7 reflecting increasing use of the PTF (61 percent of test set items for NW6 and 74 percent of test set items for NW7) as Navy co-located DDs are deleted from the NW.

- The PTF provides the best LRT solution, regardless of network permutation:

Across all NWs, the mean LRT of Min LRT solutions is lower than the mean LRT of Min Cost solutions. For NW1, NW2, NW4, NW6 and NW7 (NWs that contain the PTF), average mean LRT is about 50 percent lower at the mean of Min LRT solutions than at the mean of Min Cost solutions. Also, in comparison to NWs without the PTF (NW3 and NW5), the mean of Min LRT solutions is about 67 percent lower (1.7 days versus 4.7 days).

- As DDs in the NW decrease, the number of items with initial feasible solutions at the PTF rises:

About 35 percent of NW1 Min Cost solutions occur at Min LRT. This percentage rises (as the number of DDs falls) to 61 percent in NW 6 and 74 percent in NW7, reflecting how the ILP copes with the increasing distances (and distribution costs) between suppliers, depots and customers: it sends them to the PTF.

- Only a small portion of items are never feasible at the PTF:

For seven percent of NW1 test set items, the PTF is never a feasible solution. These line items have CONUS TP1 demand that is co-located with a depot. The PTF can never be the low cost solution for these line items since it has both a high vc (about $17 per item) and a tcout component while items available at a DD co-located with a customer have a lower average vc (vc based on weight that rises to about $18 at 125 lbs) and a tcout of zero.

5. PTF Item Characteristics

This study has thus far presented results at an aggregate level. Since the test set is made up of representative DLR line items with differing product and demand characteristics, we can exploit the individual line item results to make characterizations regarding (for the minimum cost solutions only):

- Items that always go to the PTF;

- Items that never go to the PTF; and

- Items that go to the PTF only as the number of DDs in the network decrease.

	NW1	NW2	NW3*	NW4	NW5*	NW6	NW7
Nr Depots	**24**	**9**	**8**	**7**	**6**	**18**	**3**
Percent Increase from Min Cost to Min LRT Solutions:							
Mean Cost	109.50%	110.32%	N/A	100.50%	N/A	54.23%	23.44%
Wtd Mean Cost	15.52%	14.50%	N/A	14.75%	N/A	9.09%	4.74%
Median Cost	12.00%	13.10%	N/A	11.39%	N/A	-0.29%	-0.29%
Mean LRT	-39.89%	-38.14%	N/A	38.93%	N/A	-41.19%	-39.64%
Wtd Mean LRT	-47.53%	-50.55%	N/A	-48.72%	N/A	-52.69%	-52.89%
Median LRT	-21.88%	-22.22%	N/A	-21.60%	N/A	-19.87%	-13.57%
Other Comparisons:							
% PTF Feasible at Feasible B/P	35.1%	33.33%	N/A	31.58%	N/A	61.40%	73.68%
% Never PTF Feasible	7.02%	7.02%	N/A	3.51%	N/A	0.00%	0.00%

Table 4.5: Comparison of Test Set Min Cost and Min LRT Solutions

This table provides a comparison of the statistics associated with test set Min Cost solutions and Min LRT solutions. For example, the "Mean Cost" percentages show that the mean distribution cost at Min LRT is uniformly higher than at Min Cost, ranging from 23 percent to 110 percent more. Negative percentages indicate that Min LRT solutions are lower. "% PTF Feasible at Min Cost" indicates the proportion of test set line items that have lowest distribution cost solutions at the PTF. "% Never PTF Feasible" gives the proportion of test set line items that only have positioning solutions at DDs.
* refers to NWs that do not contain the PTF.

For these purposes, we select four line items from the test set (for each category detailed above), consider their common product and demand characteristics, and try to find rationale for the positioning scheme selected by the ILP (i.e., explanations other than obvious minimum cost/ minimum LRT solution).

a. ***Items always Feasible at the PTF***

20 of the 57 (35 percent) test set line items have optimal distribution cost (First objective function) solutions at the PTF. These DLRs break down by weight into ten 75 lb items and ten 125 lb items. These items make up 54 percent of the population at those weights. No 4 lb items have optimal distribution cost solutions at the PTF. Although this study only considers one weight under 75 lbs, we can generalize that the high PTF vc (about $17 per unit) raises the

cost threshold required for lower weight items to achieve PTF feasibility. The average line item in the test set has demand at 4.8 aggregated customer locations, including 2.7 (56 percent) co-located locations and 1.5 (31 percent) overseas locations (overseas also includes 0.4 co-located locations). Table 4.6 presents four test set items that have lowest distribution cost solutions at the PTF. All of the items detailed in Table 4.6 have a relatively high percentage of demand quantity originating overseas and a relatively low percentage of co-located demand (in comparison to the average test set line item). In addition, they are all heavier items. We believe this data indicates that a combination of high weight and higher than average percentage of demand outside of co-located demand regions causes the PTF to become the optimal point of positioning.

Cog	Description	Wt (lbs)	Total Dem Qty	Co-loc Dem Qty / Overseas Dem Qty	Total/Co-loc/ Overseas Dem Regions
7R	Winch, Aircraft Mounted	75	7	4/3	3/2/1
7R	Tire, Pneumatic	125	511	13/312	10/2/4
N7R	Flow Censor	125	21	12**/9**	9/3*/3*
N7R	Pump, Fuel, Metering	125	21	8/13	4/2/2

Table 4.6: Four Test Set Line Items that Always Go to the PTF

This table presents four arbitrarily selected test set line items that have lowest distribution cost solutions at the PTF. "7R" and "N7R" refer to aviation and non-aviation DLRs, respectively. "Tot Dem Qty" represents actual demand from October 1996 to September 1998. "Co-loc Dem Qty" refers to the demand quantity originating from demand regions that are co-located with a DD. "Overseas Dem Qty" shows the demand quantity originating OCONUS. "Total Dem Regions" refers to the total aggregated demand regions, based on the 40 aggregated customer regions previously defined. "Overseas Dem Regions" refers to OCONUS customer regions. * Two of these co-located regions are also OCONUS. ** 6 of the 9 units of OCONUS customer demand co-located with a DD.

b. *Items that never go to the PTF*

15 (26 percent) of the 57 items in the test set never go to the PTF (i.e., the PTF is never the Min LRT solution). 13 (87 percent) of these 15 items weigh 4 pounds (64 percent of 4 lb items) implying that low weight (and the distribution cost advantage of the DDs over the PTF) generally results in those items having an optimal distribution network that does

not include the PTF. Table 4.7 shows four test line items that never go to the PTF. These items have almost all co-located demand (i.e., customer regions co-located with DDs). The two 4 lb items with relatively high overseas demand prefer DDs closest to AMC Aerial Ports of Embarkation (for the overseas demand quantity) to minimize transportation cost. Assuming we have perfect demand forecasts (as we do for ILP construction), line items with all co-located demand should prefer DDS over the PTF due to lower overall time and cost components.

Cog	Description	Wt (lbs)	Tot Dem Qty	Co-loc Dem Qty /Overseas Dem Qty	Total/Co-loc/ Overseas Dem Regions
7R	Drive Assy, Power	125	3	3/0	2/2/0
7R	Regulator, Electrical	4	21	15/6	7/4/3
N7R	CCA	4	33	29/9*	8/5*/2
N7R	Valve Assy	4	14	14/0	3/3/0

Table 4.7: Four Test Set Items that Never Go to the PTF

This table presents four test line line items that never have the PTF in the Min LRT solution. Definition of headings follow from Table 4.6. * One of the OCONUS demand locations, Yokosuka, is also co-located.

c. *Items that Move from DDs to the PTF as NW Size Falls*

As total DDs in the NW fall from 23 (NW1) to 3 (NW7), the number of test set line items that have Min Cost solutions at the PTF rises from 20 (35 percent) to 42 (74 percent). Table 4.8 presents four arbitrarily selected test set line items whose optimal positioning changes from DDs to the PTF as the number of DDs in the NW is decreased. These items have almost all demand in customer regions co-located with FISCs. When we delete the FISC co-located DDs from the network, optimal positioning for these items shifts, either to some of the remaining DDs (in the first, third and fourth case) or to the PTF (second case). When all Navy co-located DDs

are deleted (NWs 6 and 7), all positioning shifts to the PTF. These results seem to indicate that if DLA deletes Navy co-located DDs from their network, the PTF should become the storage site for these items.

Cog	Description	Wt (lbs)	Tot Dem Qty	Co-loc Dem Qty /Overseas Dem Qty	Total/Co-loc/ Overseas Dem Regions
7R	Sonobuoy	75	6	6/0	4/4/0
7R	Mount, Main Rear	75	13	13/0	2/2/0
N7R	Pump, Rotary	125	45	42/4*	7/5*/2*
N7R	Valve, Linear Direct	75	18	11/6*	4/3/1

Table 4.8: Items that Move from DDs to PTF as NW Size Falls

This table presents four test set items that move from DDs to the PTF as the size of the network is decreases. Definitions of headings follow from Table 4.6. * Overseas demand is co-located with DDs.

6. Impact of Deployed Demand

As mentioned previously, this study uses aggregated demand regions constructed from customer homeport locations (and not deployed locations) because we have no reliable means of determining customers' actual locations at the time of the demand. The following analysis considers the impact of deployed demand on two test set line items. For simplicity, we simulate deployed demand by shifting demand from one of the existing east or west coast CONUS ports to an OCONUS location already included for each line item. Table 4.9 presents the DLRs selected for analysis. For each scenario, we shift one third to one half of CONUS demand to overseas locations. For the first item, three units of demand shift from San Diego to Okinawa and one unit of demand shifts from Bangor to Sasebo. For the second item, seven units of demand shift from Norfolk to Manama (Bahrain) and one item each shift from Pearl Harbor and San Diego to Sasebo. Table 4.10 shows the cost and LRT associated with the original scenario and the shifted demand scenarios. For product 11, the effect of the demand shift is simply increasing cost and

LRT. We expect that such a shift may cause the PTF to become the optimal solution. However, this item weighs 4 lbs and as shown previously, these lower weight items do not tend to go to the PTF because of their relatively high vc and higher associated transportation cost. For example, to ship a 4 lb item from Norfolk to Bahrain using AMC costs $9.36. FedEx charges $26.00 for the same shipment, but their rate applies from all CONUS locations. The PTF does not seem to be the optimal solution for most low weight items.

Nr	Cog	Description	Wt (lbs)	Tot Dem Qty	Co-loc Dem Qty /Overseas Dem Qty	Total/Co-loc/ Overseas Dem Regions
11	7R	Regulator, Electrical	4	21	15/6	7/4/3
24	N7R	Image Intensifier N	75	42	31/5	11/7/4

Table 4.9: Items selected to Test the Impact of Shifting Demand Overseas

This table presents two line items arbitrarily selected from the test set for testing of "simulated" deployed demand. Definition of headings follows from Table 4.6. "Nr" refers to the number of the test set line item as listed in the Appendix, Table 1. * Four of these items have co-located overseas demand.

Nr	Description	NW1	NW2	NW3	NW4	NW5	NW6	NW7
11	Old Avg Dist Cost ($/lb)	2.19	2.19	2.19	2.23	2.23	2.75	2.79
	New Avg Dist Cost ($/lb)	2.73	2.73	2.73	2.75	2.75	3.13	3.18
	% Cost Change	**25%**	**25%**	**25%**	**23%**	**23%**	**14%**	**14%**
	Old Avg LRT (Days)	3.74	3.48	4.05	4.18	4.18	4.73	5.06
	New Avg LRT (Days)	4.76	5.23	5.23	5.43	5.43	5.43	5.81
	% LRT Change	**27%**	**50%**	**29%**	**30%**	**30%**	**15%**	**15%**
24	Old Avg Cost ($ per lb)	0.92	0.94	0.94	0.96	0.96	1.41	1.41
	New Cost ($ per lb)	1.38	1.38	1.55	1.38	1.58	1.38	1.38
	% Cost Change	**50%**	**50%**	**61%**	**50%**	**65%**	**-2%**	**-2%**
	Old Avg LRT (Days)	3.12	3.07	3.07	3.29	3.29	1.14	1.14
	New Avg LRT (Days)	1.38	1.38	4.71	1.38	4.93	1.38	1.38
	% LRT Change	**-56%**	**-56%**	**53%**	**-58%**	**50%**	**21%**	**21%**

Table 4.10: Comparison of Before and After Results for Shifted Demand

This table presents the before ("Old") and after ("New") distribution cost and LRT for two arbitrarily selected test set line items. In the "New" scenario, demand has been shifted overseas to simulate deployed demand.

For Product 24, we shift ten of 42 units of demand to overseas (6 units of demand are already overseas) locations. This line item has a unit weight of 75 lbs. The effect of the demand shift causes the PTF to always be the optimal solution. As shown in Table 4.12, the demand shift causes average distribution cost to rise 50 percent for scenarios one to five although average LRT drops correspondingly for those NWs containing the PTF. The PTF seems to be a more competitive solution for optimally satisfying overseas demand when the unit weight is heavier.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis shows how the Navy can reduce both average DLR distribution cost and LRT by considering distribution points that are not co-located with Navy activities. This conclusion comes from extensive analysis of seven distribution network permutations using the ILP described herein. This study uses conservative assumptions that favor the government (DDs and the transportation system) and therefore provides an optimistic view of the relationships that exist between elements of the distribution network. This thesis derives a 57 DLR line item test set that is representative of DLRs most likely to benefit from re-positioning: items with recent historical demand and high projected demand (four or more per year). It also derives a simplified six-mode transportation scheme and an aggregated customer scheme (40 regions), rendering an ILP that is simple to use and that captures the essence of the distribution network. Extensive comparisons between the seven networks at Min Cost (lowest distribution cost) and Min LRT (minimum LRT) imply that:

- the PTF is often the low cost solution;
- low weight items are not usually the best candidates for PTF stockage; and
- deleting Navy co-located DDs from the network barely affects distribution cost but the associated average LRT decreases drastically because the PTF becomes the optimal solution in most cases.

This study suggests that the PTF is under-utilized by NAVICP. For all network iterations, the PTF is the lowest cost solution at least 30 percent of the time. NAVICP currently has or is in process of moving about 800 line items to the PTF. The study derives this test set from a database of about 9700 line items with recent historical demand, projected annual demand of four or more and a unit weight less than 150 lbs, nominally suggesting more than 3,000 potential PTF candidates.

B. RECOMMENDATIONS

Because of the limited nature of this study and the lack of readily available data, we use simplified approaches for transportation modes and the development of DPT, DTOUT, TCIN and TCOUT tables. This data captures the essential relative relationships among the elements of the network, providing suggestive but not exact answers. Therefore, this study recommends that the transportation rates and modes used by DOD be examined further and composite rates and modes be developed to better refine those already used as data in the ILP.

The ILP suggested by this study is useful for determining optimal positioning for one or more DLR line items and is one tool that should be utilized in selecting DLR line items for the PTF.

LIST OF REFERENCES

Ackert, L., Electronic Mail between Author and LCDR Ackert, SC, USN, stationed at NAVICP-P, 20 September 1999.

Air Mobility Command (AMC), Channel Performance and Analysis Report for 2nd Quarter 1999, undated 1999a.

AMC, *World Wide Express (WWX) Price Estimator*, www.amc.af.mil, March 1999b.

Andersen Consulting, Robeson, J. and Copacino, W. (editors), *The Logistics Handbook*, The Free Press, New York, NY, 1994.

Ballou, R., *Business Logistics Management*, Prentice Hall, Englewood Cliffs, New Jersey, 1992.

Ballou, R., "Measuring Transport Costing Error in Customer Aggregation for Facility Location", *Transportation Journal*, Spring 1994, pp. 49 - 59.

Bender, P., "Logistics System Design" in Robeson J.F. and House, R.G. (editors), *The Distribution Handbook*, The Free Press, New York, NY, 1985.

Boylan, K., Electronic Mail between Author and Mr. Boylan, Naval Transportation Support Center (NAVTRANS) Code 02F, 14 June 1999.

Current, J. and Schilling, D., "Elimination of Source A and B Errors in P-Median Location Problems", *Geographical Analysis*, Ohio State University Press, April 1987,pp. 95 - 110.

Defense Logistics Agency, Brief, *DLA Premium Service Program Partnership for Excellence*, Susquehanna PA 1998a.

Defense Logistics Agency, DD Form 805, *DLA Storage Space Utilization*, 30 September 1998b.

Defense Logistics Agency, Online Brochure, *Distribution Support*, www.ddc.dla.mil, 14 January 1999a.

Defense Logistics Agency, Paper, *Premium Service.........The Future*, Susquehanna, PA, February 1999b.

Defense Logistics Agency, Website, www.daas.dla.mil , 1999c.

Department of Defense, Materiel Distribution Study Vol I, July 1978.

Department of Defense Materiel Management Regulation 4140.1-R, Appendix 8, UMMIPS Time Standards, July 1998.

Department of Defense, 1999 DOD Airlift Rate Tables, October 1998.

Diehl, T, NAVICP-M, Telephone conversation between Author and Ms. Diehl NAVICP Code M0415.03, 31 AUG 1999.

Emerick, R., Electronic Mail between Author and Mr. Emerick NAVICP Code M0411.02, 13 May 1999a.

Emerick, R., Electronic Mail between Author and Mr. Emerick NAVICP Code M0411.02 , 24 May 1999b.

Engelman, J., Conversation between Author and Mr. Engelman NAVICP Code M041.X, November 1998.

Engelman, J., Electronic Mail between Author and Mr. Engelman NAVICP Code M041.X, 22 February 1999.

Evans, G., Telephone conversation between Author and Mr. Evans NAVICP Code M0414.02, 31 August 1999.

Geoffrion, A. and Powers, R., "Twenty Years of Strategic Distribution System Design: An Evolutionary Perspective", *Interfaces*, September-October 1995, pp. 105 - 127.

Gotwalt, M. , *Cost Benefit Analysis of the Navy Option to The Defense Supply Center Richmond Premium Service Contract*, Coopers & Lybrand, McLean, Virginia, 19 June 1998.

Hadley, G. and Whitin T., *Analysis of Inventory Systems*, Prentice Hall, Englewood Cliffs, N.J., 1963.

Hobbs, J. and Lanagan, T., *Stockage Location Policy Analysis*, Report No. DLA-92-P10148, Operations Research and Economic Analysis Office, Defense Logistics Agency, 1992.

Holmes, R., LT, USN, *A Multi-Commodity Network Design for the Defense Logistics Agency*, Master's Thesis in Operations Research, Naval Postgraduate School, 1994.

House, R. and Jamie, K., "Measuring the Impact of Alternative Market Classification Systems in Distribution Planning", Journal of Business Logistics, Vol. 2, No. 2, 1981, pp. 1 - 31.

Kasilingam, R., *Logistics and Transportation*, Kluwer Academic Publishers, Boston, Ma, 1998.

KPMG Peat Marwick LLP, *Optimization Study for Defense Distribution System*, February 1995.

MacMillan, K., Electronic Mail between Ms. T. Reed Fleet Materiel Support Office (FMSO) Code 9622 and Mr. MacMillan NAVICP Code 05712.10, 18 December 1998.

MacMillan, K. Electronic Mail between Author and Mr. MacMillan NAVICP Code 05712.10, 01 September 1999.

Magee, J., Copacino W., Rosenfield, D., *Modern Logistics Management,* John Wiley & Sons, New York, NY, 1985.

Naval Inventory Control Point, Data Summary, untitled, Mechanicsburg, PA, 1997.

Naval Supply Systems Command, Brief, *Inventory...Logistics Response Time*, Washington, D.C. , October 1998.

Naval Supply Systems Command, NAVSUP P-485, *Afloat Supply Procedures*, July 1999.

Naval Supply Systems Command, NAVSUP P-542 (Draft), *Uniform Inventory Control Program Reference Document*, 15 December 1996.

Naval Supply Systems Command, NAVSUP P-553, *Inventory Management*, Washington, D.C., June 1992.

Porter, B., Emerick, R., Brief, *Premium Service*, Naval Inventory Control Point, Mechanicsburg, PA, October 1998.

Robillard, G., Point Paper, *Use of Premium Service Transportation*, Naval Inventory Control Point, Mechanicsburg, PA, 06 January 1997.

Sample, R., Telephone Conversation between Author and LTCOL Sample, USAF, PTF Program Manager, Defense Distribution Center, February 1999.

United Parcel Service (UPS), *Quick Rate Calculator*, www.ups.com , June to August 1999.

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APPENDIX

This appendix contains three tables. A description of these tables and their elements follow:

Table 1: Breakdown of Proportion of Demand Weight by Weight Category for Top 14 Locations

This table presents a breakdown of the proportion of database demand weight by location by cog for those locations with a two-year demand weight exceeding 100,000 lbs. Each weight category entry specifies the total proportion of the demand weight occurring in a particular city. For example, San Diego has 26 percent of the total demand for DLR line items weighing less than one lb and 21 percent of the total demand for DLR line items weighing between 50 and 100 lbs. "Mean" represents the mean percentage of total demand experienced by a particular city. For example, 20 percent of total DLR demands originate from customers homeported in San Diego. "Median" is the median of weight category values by city. Variance and Standard Deviation are derived from weight category values by city. The units of variance are squared proportion. "COV" refers to the Coefficient of Variation calculated as Standard Deviation / Mean. For all Cogs, more than 85 percent of demand occurs within cities that have COVs less than 25 percent. For 7R and N7R items, 79 percent and 94 percent of demand respectively, occurs within cities with COVs less than 25 percent. These low COVs demonstrate that demand location has little influence on the unit weight demanded.

Table 2: Listing of Aggregated Customer Regions

This table presents a list of the aggregated customer regions used in the ILP for demand. Aggregate locations are found in CONUS using the first three digits of the zip code: they are found OCONUS using the closest likely POE.

Table 3: Description of Test Set Line Items

This table provides a description of the test set data used to populate the ILP. A brief description follows:

- "Cog" refers to materiel cognizance symbol;

- "7R" and "N7R" represent aviation and non-aviation items respectively;

- "FSCM" and " NIIN" make up the NSN;

- "Wt" is the item's unit weight in pounds (lbs);

- "Cost" represents the item's standard unit price;

- "Dem" represents total quantity demanded from October 1996 to September 1998, taken from NAVICP Demand History;

- "WOR" (Wear Out Rate) indicates the probability an item does not survive use, transportation or storage: WOR provided by NAVICP;

- "CRR" (Carcass Return Rate) is the probability a failed item is turned into a shore repair facility;

- "RSR" is the probability an item survives the repair process: RSR provided by NAVICP;

- "NPR" (New Procurement Rate) represents the proportion of inventory that must be obtained through new procurement: Calculated as 1 - (CRR*RSR);

- "Survival Rate" represents the proportion of inventory that must be obtained from repair depots: Calculated as 1 - NPR;

- "DOP UIC" and "DOP Zip" give the name and location of the Designated Overhaul Point used as a source for repaired items: DOP information obtained from NAVICP;

- "CAGE" identifies the item's manufacturer and location: Obtained from NAVICP; Certain items lack current CAGE information (identified with "N/A"); For this study, we assume that a lack of manufacturer forces the depot to manufacture the item.

Table 1
Breakdown of Proportion of Demand Weight by Weight Category for Top 14 Locations

All 7 Cogs

Weight Categories (Pounds)

	Less than 1	1 to 2	2 to 5	5 to 10	10 to 20	20 to 50	50 to 100	100 to 150	Mean	Median	Variance	Std Dev	COV
San Diego CA	0.26	0.22	0.21	0.18	0.21	0.17	0.21	0.14	0.2015	0.2128	0.0014	0.0377	0.1869
Norfolk VA	0.16	0.15	0.14	0.13	0.16	0.15	0.13	0.11	0.1407	0.1424	0.0003	0.0183	0.1300
Jacksonville FL	0.15	0.16	0.17	0.20	0.17	0.16	0.18	0.22	0.1757	0.1705	0.0005	0.0219	0.1245
Bangor WA	0.07	0.07	0.07	0.07	0.05	0.06	0.05	0.05	0.0623	0.0648	0.0001	0.0098	0.1569
Whidbey Is WA	0.07	0.06	0.07	0.06	0.05	0.07	0.07	0.06	0.0623	0.0646	0.0000	0.0059	0.0954
Lemoore CA	0.02	0.02	0.03	0.03	0.02	0.04	0.02	0.05	0.0282	0.0251	0.0001	0.0087	0.3098
Oceana VA	0.02	0.01	0.02	0.02	0.02	0.03	0.04	0.01	0.0215	0.0175	0.0001	0.0109	0.5072
Pearl Harbor HI	0.05	0.06	0.06	0.07	0.05	0.06	0.06	0.05	0.0576	0.0564	0.0000	0.0054	0.0945
Yokosuka JA	0.05	0.05	0.03	0.03	0.03	0.04	0.04	0.03	0.0368	0.0354	0.0001	0.0075	0.2036
Misawa JA	0.01	0.03	0.02	0.02	0.03	0.02	0.03	0.05	0.0279	0.0267	0.0001	0.0100	0.3578
Iwakuni JA	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.03	0.0237	0.0231	0.0000	0.0053	0.2256
Okinawa JA	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.05	0.0276	0.0262	0.0001	0.0105	0.3803
Atsugi JA	0.01	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.0137	0.0136	0.0000	0.0056	0.4059
Diego Garcia	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.0126	0.0107	0.0001	0.0077	0.6142
Others	0.10	0.12	0.10	0.12	0.11	0.11	0.09	0.11	0.1079	0.1087	0.0001	0.0092	0.0848
Totals	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					

7R Cogs Only

	Less than 1	1 to 2	2 to 5	5 to 10	10 to 20	20 to 50	50 to 100	100 to 150	Mean	Median	Variance	Std Dev	COV
San Diego CA	0.25	0.21	0.22	0.19	0.22	0.16	0.22	0.12	0.1963	0.2114	0.0018	0.0419	0.2135
Norfolk VA	0.06	0.06	0.07	0.07	0.12	0.08	0.09	0.05	0.0763	0.0688	0.0005	0.0234	0.3064
Jacksonville FL	0.21	0.23	0.22	0.27	0.21	0.20	0.20	0.25	0.2257	0.2188	0.0006	0.0246	0.1090
Bangor WA	0.09	0.08	0.07	0.06	0.05	0.07	0.05	0.05	0.0640	0.0656	0.0002	0.0156	0.2444
Whidbey Is WA	0.07	0.07	0.08	0.07	0.06	0.08	0.07	0.06	0.0715	0.0735	0.0001	0.0102	0.1424
Lemoore CA	0.05	0.04	0.04	0.04	0.03	0.05	0.03	0.06	0.0426	0.0415	0.0001	0.0098	0.2297
Oceana VA	0.04	0.02	0.03	0.02	0.03	0.05	0.05	0.01	0.0318	0.0268	0.0002	0.0137	0.4298
Pearl Harbor HI	0.02	0.04	0.03	0.05	0.04	0.05	0.04	0.04	0.0386	0.0411	0.0001	0.0094	0.2429
Yokosuka JA	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.0256	0.0253	0.0000	0.0043	0.1661
Misawa JA	0.03	0.05	0.04	0.04	0.04	0.03	0.04	0.06	0.0415	0.0403	0.0001	0.0100	0.2414
Iwakuni JA	0.05	0.03	0.04	0.04	0.02	0.04	0.03	0.04	0.0357	0.0379	0.0001	0.0080	0.2250
Okinawa JA	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.06	0.0403	0.0381	0.0001	0.0101	0.2517
Atsugi JA	0.02	0.02	0.02	0.02	0.04	0.02	0.01	0.02	0.0205	0.0191	0.0000	0.0067	0.3263
Diego Garcia	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.04	0.0176	0.0157	0.0001	0.0091	0.5168
Others	0.05	0.08	0.05	0.06	0.07	0.07	0.08	0.11	0.0721	0.0729	0.0004	0.0195	0.2706
Totals	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					

Not 7R Cog

	Less than 1	1 to 2	2 to 5	5 to 10	10 to 20	20 to 50	50 to 100	100 to 150	Mean	Median	Variance	Std Dev	COV
San Diego CA	0.27	0.25	0.20	0.18	0.20	0.20	0.19	0.20	0.2117	0.2030	0.0009	0.0296	0.1398
Norfolk VA	0.24	0.26	0.25	0.24	0.27	0.29	0.27	0.32	0.2690	0.2626	0.0008	0.0276	0.1025
Jacksonville FL	0.09	0.08	0.07	0.06	0.07	0.08	0.08	0.07	0.0765	0.0760	0.0001	0.0105	0.1377
Bangor WA	0.05	0.05	0.07	0.09	0.06	0.05	0.07	0.07	0.0649	0.0610	0.0002	0.0150	0.2307
Whidbey Is WA	0.06	0.04	0.04	0.03	0.03	0.03	0.05	0.08	0.0464	0.0389	0.0003	0.0181	0.3891
Lemoore CA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0003	0.0003	0.0000	0.0003	1.0715
Oceana VA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0013	0.0010	0.0000	0.0014	1.1064
Pearl Harbor HI	0.08	0.08	0.11	0.11	0.10	0.10	0.10	0.08	0.0936	0.0985	0.0001	0.0116	0.1235
Yokosuka JA	0.07	0.07	0.05	0.05	0.05	0.06	0.06	0.05	0.0565	0.0548	0.0001	0.0099	0.1749
Misawa JA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0004	0.0004	0.0000	0.0003	0.9511
Iwakuni JA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0015	0.0014	0.0000	0.0010	0.6805
Okinawa JA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0010	0.0010	0.0000	0.0008	0.8155
Atsugi JA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.0001	2.8284
Diego Garcia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0014	0.0015	0.0000	0.0008	0.5591
Others	0.14	0.16	0.19	0.23	0.22	0.17	0.17	0.13	0.1756	0.1698	0.0013	0.0364	0.2073
Totals	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					

Table 2
Listing of Aggregated Customer Regions

Nr	City/Locality	State/Country
1	Manama	Bahrain
2	Lemoore	CA
3	Oceanside	CA
4	Pt Mugu	CA
5	San Diego	CA
6	Santa Clara	CA
7	Groton	CT
8	Jacksonville	FL
9	Pensacola	FL
10	King's Bay	GA
11	Marietta	GA
12	Agana	Guam
13	Pearl Harbor	HI
14	Diego Garcia	British Protectorate
15	La Madellena	Italy
16	Sigonella	Italy
17	Atsugi	Japan
18	Iwakuni	Japan
19	Misawa	Japan
20	Okinawa	Japan
21	Sasebo	Japan
22	Yokosuka	Japan
23	New Orleans	LA
24	Andrews AFB	MD
25	Brunswick	ME
26	Meridian	MS
27	Pascagoula	MS
28	Portsmouth	NH
29	Colts Neck	NJ
30	Newburg	NY
31	Christchurch	NZ
32	Willow Grove	PA
33	Charleston	SC
34	Fort Worth	TX
35	Ingleside	TX
36	Norfolk	VA
37	Oceana	VA
38	Bangor	WA
39	Whidbey Island	WA
40	China Lake	CA

Table 3
Description of Test Set Line Items

Nr	COG	GP	FSCM	NIIN	DESCRIPTION	Weight (LBs)	CUBE	COST	DEM	CRR	RSR	NPR	SR	DOP UIC	DOP ZIP	CAGE	CONTRACTOR	CITY
1	7R	16	1660	00-009-5623	Reg, Air Pressure	4	0.35	5650	9	0.99	0.99	0.0199	0.9801	N00146	28533	70210	Allied Signal	Torrance CA
2	7R	16	1680	01-129-8118	Winch,Aircraft Moun	75	14.89	40380	7	0.98	0.98	0.0396	0.9604	N00146	28533	08484	Breeze-Eastern	Union NJ
3	7R	16	1650	00-004-9788	Hydraulic Aileron B	125	10.05	32480	2	0.99	0.99	0.0199	0.9801	N68836	32212	NA	No Cage Listed	NA
4	N7R	16	1650	01-309-7485	Servovalve, Hydraulic	4	0.43	5360	9	0.92	0.92	0.1536	0.8464	2W364	84119	2W364	Raytheon	Salt Lake City UT
5	7R	66	6620	00-005-8610	Transmitter, Rate of	4	0.42	7510	4	0.59	0.59	0.6519	0.3481	N00244	92132	97324	Ametek	Wilmington MA
6	7R	66	6685	01-156-9206	Thermocouple Unit	75	6.71	39870	17	0.74	0.74	0.4524	0.5476	Q35012	33758	35012	Smith Industries	Clearwater FL
7	7R	66	6625	01-301-6090	Analyzer, Spectrum	129	8.66	99510	18	0.88	0.88	0.2256	0.7744	N00244	92132	3F050	Tucker Electric	Garland TX
8	N7R	66	6605	00-861-7353	Bearing Circle	4	0.4	1390	10	0.55	0.85	0.5325	0.4675	Q6U479	8071	6U479	CEI Inc	Pitman NJ
9	N7R	66	6625	01-100-0306	Printer	75	10.05	31100	38	1	1	0	1	Q54418	36043	54418	Miltope Corp	Hope Hall AL
10	N7R	66	6680	01-207-0128	Flow Sensor	115	20.61	33620	21	0.75	0.75	0.4375	0.5625	Q03538	13221	03538	Lockheed Martin	Syracuse NY
11	7R	61	6110	00-165-3835	Regulator, Electrical	4	0.59	2490	21	0.86	0.86	0.2604	0.7396	N00244	92132	83298	Allied Signal	Tucson AZ
12	7R	61	6115	00-946-8441	Generator, Alternating	75	6.79	31730	20	0.01	1	0.99	0.01	W20859	5402	5Y039	GE	Burlington VT
13	7R	61	6115	01-129-0138	Generator, Alternating	128	7.58	21290	111	0.93	0.93	0.1351	0.8649	N00244	92132	07639	Smith Industries	Vandalia OH
14	N7R	61	6130	00-009-0272	Power Supply Assy	4	0.2	2580	20	0.95	1	0.05	0.95	N46433	92135	0AU52	GCB Corp	Wilmington CA
15	N7R	61	6110	01-399-7916	Distrib Box	73	5	39780	7	0.91	0.92	0.1628	0.8372	N60701	90740	NA	No Cage Listed	NA
16	N7R	61	6110	01-333-1738	Regulator, Voltage	125	7.84	48640	33	1	1	0	1	5D744	1776	5D744	Raytheon	Sudbury MA
17	7R	26	2620	00-277-5398	Tire, Pneumatic	11.3	1.08	114	1345	0.01	1	0.99	0.01	N00244	92132	0A1K8	Michelin	Greenville SC
18	7R	26	2620	00-834-6673	Tire, Pneumatic	80	8.25	413	123	0.01	1	0.99	0.01	FB2029	95652	NA	No Cage Listed	NA
19	7R	26	2620	00-928-4502	Tire, Pneumatic	120	10.99	976	511	0.55	0.55	0.6975	0.3025	N00244	92132	11809	Thompson Aerospace	Miami FL
20	7R	58	5821	00-072-5454	Receiver, Radio	4	1.63	17240	24	0.99	0.99	0.0199	0.9801	N00244	92132	55901	Dare Electric	Troy OH
21	7R	58	5845	01-257-2714	Sonobuoy	75	4.56	194280	6	0.98	0.98	0.0396	0.9604	N68836	32212	94987	Cubic Defense Systems	San Diego CA
22	7R	58	5841	01-248-1978	Transmitter-Modulat	124.5	14.08	72490	7	0.97	0.97	0.0591	0.9409	N00244	92132	96214	Raytheon	McKinney TX
23	N7R	58	5805	00-064-8201	Switch, Telephone, Se	4	0.46	539	33	0.92	0.92	0.1536	0.8464	N39826	7737	14100	Stromberg-Carlson	Lake Mary FL
24	N7R	58	5855	01-352-7033	Image Intensifier N	80	1.97	36430	42	0.84	0.85	0.286	0.714	N00164	47522	NA	No Cage Listed	NA
25	N7R	58	5895	01-201-0981	Amplifier, RF	109.5	9.57	25150	12	1	1	0	1	N46433	92135	NA	No Cage Listed	NA
26	7R	28	2840	00-608-7627	Support, Turbine Com	4	0.77	725	19	0.01	1	0.99	0.01	W20860	53401	83829	Styberg Engineering	Racine WI
27	7R	28	2840	00-143-4382	Mount, Main Rear	75	10.05	58830	13	0.66	0.66	0.5644	0.4356	N68836	32212	NA	No Cage Listed	NA
28	7R	28	2840	01-146-0278	Rotor Assy, Power	125	12.7	61740	5	0.98	0.98	0.0396	0.9604	N00146	28533	99207	GE	Lynn MA
29	N7R	28	2840	00-505-8319	roud Segment, Turbine	4	0.19	435	9	0.84	0.85	0.286	0.714	GE	45215	01993	Ferrotham	Cleveland OH
30	N7R	28	2825	01-057-8461	Bearing, Lining Inst	73.4	1.06	4560	7	0.57	0.76	0.5668	0.4332	Q98720	77043	0BR59	Dresser Rand	Wellsville NY
31	N7R	28	2825	01-058-1756	Bearing, Lining Inst	124	3.31	2950	14	0.84	0.85	0.286	0.714	Elec Boat	6349	07325	Pioneer Motor Bearing	San Francisco CA
32	7R	59	5998	00-004-9637	CCA	4	0.4	2180	8	0.99	0.99	0.0199	0.9801	Q80249	11714	26512	Northrop Grumman	Bethpage NY
33	7R	59	5985	00-434-9107	Dummy Load, Elec	75	22.34	32190	7	0.65	0.65	0.5775	0.4225	N00244	92132	35388	No Cage Listed	NA
34	7R	59	5985	01-257-6715	Antennae Assy	120	39.59	335170	12	0.96	0.96	0.0784	0.9216	Q76301	90245	82577	Hughes Aircraft	El Segundo CA
35	N7R	59	5998	00-006-4285	CCA	4	0.19	2660	33	0.77	0.81	0.3763	0.6237	Raytheon	23511	2F259	Raytheon	Fullerton CA
36	N7R	59	5960	01-261-5600	Indicator, Video	70	9.85	5030	27	1	1	0	1	C48301	8059	02769	Lockheed Martin	Moorestown NJ
37	N7R	59	5915	01-020-6171	Filter Assy, Elec	125	22.34	3920	11	0.9	0.9	0.19	0.81	N46433	92135	23939	Captor Corp	Tipp City OH
38	7R	29	2915	00-566-0334	Valve, Fuel, Tanktra	4	0.15	5870	149	0.94	0.94	0.1164	0.8836	N68836	32212	59211	Parker Hannifan	Irvine CA
39	7R	29	2915	01-074-9903	Fuel Control, Main, T	75	6.29	26160	37	0.99	0.99	0.0199	0.9801	C60002	11714	26512	Northrop Grumman	Bethpage NY
40	7R	29	2915	01-351-4894	Fuel Control, Main, T	127	19.01	243810	6	0.99	0.99	0.0199	0.9801	C24978	85285	02LU7	Allied Signal	Tempe AZ
41	N7R	29	2910	01-050-7648	Pump, Fuel	4	0.38	1600	20	1	1	0	1	81833	44143	81833	Transdigm	Cleveland OH
42	N7R	29	2950	01-416-9324	Turbosupercharger	78	8	6150	6	0.89	0.92	0.1812	0.8188	7R034	78408	7R034	Diesel Injection Sales	Corpus Cristi TX
43	N7R	29	2910	01-180-0805	Pump, Fuel, Metering	142.51	3.17	7840	21	0.82	0.85	0.303	0.697	82796	53511	82796	Coltec Industries	Beloit WI
44	7R	15	1560	00-153-1128	Door, Access	4	2.24	12830	4	0.63	0.63	0.6031	0.3969	N68836	32212	NA	No Cage Listed	NA
45	7R	15	1560	01-246-6434	Support, Structural	75	50	239540	5	0.95	0.95	0.0975	0.9025	N00146	28533	76301	McDonnell Douglas	St Louis MO
46	7R	15	1560	00-866-6688	Tank, Fuel, Aircraft	125	34.72	15210	6	0.01	0.01	0.9999	1E-04	N68836	32212	05476	American Fuel Cell	Magnolia AR
47	7R	43	4320	01-146-8226	Pump, Rotary	3.78	1.01	4360	21	0.01	0.01	0.9999	1E-04	N68836	32212	86329	Parker Hannifan	Ayer MA
48	7R	43	4320	00-575-5019	Pump, Rotary	72	15.46	5420	2	0.95	0.95	0.0975	0.9025	N68836	32212	NA	No Cage Listed	NA
49	7R	43	4320	01-202-7214	Drive Assy, Power	133	4.68	11330	3	0.93	0.93	0.1351	0.8649	N00146	28533	93953	Melstrom Mfg	Farmingdale NJ
50	N7R	43	4320	01-182-0200	Pump, Reciprocating	4	0.07	10150	74	0.85	0.85	0.2775	0.7225	Prkr Han	92709	62186	Saint Lawrence Inc	Romulus MI
51	N7R	43	4330	00-218-5956	Bowl Assy	76	11.42	9580	51	1	1	0	1	6K044	23323	6K044	Alfa-Laval Separator Inc	Chesapeake VA
52	N7R	43	4320	01-068-4706	Pump, Rotary	120	2.29	6360	45	0.95	0.95	0.0975	0.9025	52330	15238	52330	Megator Corp	Pittsburgh PA
53	7R	48	4820	00-021-7145	Valve Assy	4	0.21	4420	18	0.94	0.94	0.1164	0.8836	N68836	32212	73030	United Technologies	Windsor Locks CT
54	7R	48	4820	01-256-8145	Vibration Supp	65.85	1.74	59580	4	0.99	0.99	0.0199	0.9801	C24444	76053	97499	Textron Bell Helicopter	Hurst TX
55	N7R	48	4820	01-117-2219	Valve Assy	4	0.59	2970	14	0.99	1	0.01	0.99	N46433	92135	0TFM1	Woodward Governor	Loveland CO
56	N7R	48	4820	01-222-6257	Valve, Linear Direct	75	1.15	32420	18	1	1	0	1	N46433	92135	59364	Allied Signal	Tempe AZ
57	N7R	48	4820	00-752-9438	alve, Regulating, Flow	133.33	0.54	4500	12	0.76	0.76	0.4224	0.5776	N46433	92135	03847	Warren Controls	Broadway NJ

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